Creative Discovery in Architectural Design Processes

An empirical study of *procedural* and *contextual* components

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I, Tamer Abdelazim Ismail El-Khouly, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis

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Abstract

This research aims to collect empirical evidence on the nature of design by investigating the question: *What role do procedural activities* (where each design step reflects a unit in a linear process) *and contextual activities* (an action based on the situation, environment and affordances) *play in the generation of creative insights, critical moves, and the formation of design concepts in the reasoning process?* The thesis shows how these activities can be identified through the structure of a linkograph, for better understanding the conditions under which creativity and innovation take place.

Adopting a mixed methodology, a deductive approach evaluates the existing models that aim to capture the series of design events, while an inductive approach collects data and ethnographic observations for an empirical study of architectural design experiments based on structured and unstructured briefs. A joint approach of quantitative and qualitative analyses is developed to detect the role of evolving actions and structural units of reasoning, particularly the occurrence of creative insights ('eureka' and 'aha!' moments) in the formation of concepts by judging the gradual transformation of mental imagery and external representations in the sketching process.

The findings of this research are:

(1) For any design process procedural components are subsets in solving the design problem for synchronic concept development or implementation of the predefined conceptual idea, whereas contextual components relate to a comprehensive view to solve the design problem through concept synthesis of back- and forelinking between the diachronic stages of the design process.

(2) This study introduces a new method of looking at evolving design moves and critical actions by considering the time of emergence in the structure of the reasoning process. *Directed linkography* compares two different situations: the first is synchronous, looking at relations back to preceding events, and the second is diachronic, looking at the design state after completion. Accordingly, creative insights can be categorised into those emerging in incremental reasoning to *reframe the solution*, and sudden mental insights emerging in non-incremental reasoning to *restructure the design problem* and *reformulate the entire design configuration*.

(3) Two architectural designing styles are identified: some architects define the design concept early, set goals and persevere in framing and reframing this until the end, whereas others initiate the concept by designing independent conceptual elements and then proceed to form syntheses for the design configuration. Sudden mental insights are most likely to emerge from the unexpected combination of synthesis, particularly in the latter style.

In its contribution to *design research* and *creative cognition* this dissertation paves the way for a better understanding of the role of reflective practices in design creativity and cognitive processes and presents new insights into what it means to think and design as an architect.

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To the Soul of my Father
&
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Prior publications

The following published papers are directly related to the work presented in this dissertation, and contain material presented here:

El-Khouly, T., and Penn, A. (2013) 'Directed Linkography and Syntactic Analysis: Comparing Synchronous and Diachronic Effects of Sudden Emergence of Creative Insights on the Structure of the Design Process'. In Digital Proceedings of the 9th Space Syntax Symposium (SSS9 2013), 31 October – 3 November 2013, Seoul, Korea, pp. 059:1 – 059:24

El-Khouly, T. (2013) 'The Structure of Reasoning and Emergence of Creative Insights in Architectural Design Process'. In Digital Proceedings of the 5th International Congress of International Association of Societies of Design Research (IASDR 2013), 26–30 August 2013, Tokyo, Japan, 1309-1, pp. 1-12

El-Khouly, T., and Penn, A. (2012) 'On an Integrated Analytical Approach to Describe Quality Design Process in Light of Deterministic Information Theory'. In Digital Proceedings of the 5th International Conference on Design Computing and Cognition (DCC'12), College Station, Texas, 5–9 June, 2012, pp. 36:1 – 36:20

El-Khouly, T., and Penn, A. (2012) 'Order, Structure and Disorder in Space Syntax and Linkography: Intelligibility, Entropy, and Complexity Measures'. In Proceedings of the 8th Space Syntax Symposium, Santiago De Chile, (SSS8 2012), pp. 8242:1 – 22.

El-Khouly, T. (2010) 'Mind and Drawing: The Mutual Effect of Multiple Cognitive Structures In The Formation of Novel Concepts'. A Poster in the 4th Conference of Design Computing and Cognition, (DCC 2010), University of Stuttgart, Germany.

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Abdelmohsen, S., and El-Khouly, T. (2009) 'Representing Reflective Practice in a Remote Design Collaboration Process'. In Digital Proceedings of the International Association of Societies of Design Research (IASDR 2009), COEX, Seoul, Korea: 1317–1326.

El-Khouly, T. (2009) 'Examining the Effect of Idea Exchange Through Various External Representations — Digitally Mediated Environments and Design Tools — On the Ability to Overcome the Fixation Effect: A Remotely-Located Collaborative Case'. Unpublished Pilot Study, Bartlett School of Graduate Studies, University College London UCL.

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Executive Summary

There has been great interest in the field of design research in understanding the nature of design processes and creative discovery. Defining 'what design is about' is an ongoing debate in which two views have prevailed: the *technical rationality* of *Simonian positivism* viewed design as *concerned with how things ought to be* (Simon, 1969); and the *epistemology of practice* of *Schönian constructivism* looked at design as a *reflective conversation with the situation* (Schön, 1983). The difference between these views is an example of the paradox in design research. According to the first view, design is an incremental, procedural process where the relation between the *contents* (artefacts of design) and *structure* (reasoning process) is *hierarchical*, whereas according to the second view, design is a reflective practice, contextual action based on environment, and the relation between *contents* and *structure* is *transformational*. The main focus here is on the evolution of critical actions and their role on the formation of conceptual ideas in the architectural reasoning process.

This research aims to collect empirical evidence on the nature of design by investigating the question: *What role do procedural activities* (where each design step reflects a unit in a linear process) *and contextual activities* (an action based on the situation, environment and affordances) *play in the generation of creative insights, critical moves, and the formation of design concepts in the reasoning process?* By identifying these activities we aim to understand the context behind the emergence of creative insights, critical moves, and the formation of design concepts in the design reasoning process. The thesis shows how these can be identified through the structure of a linkograph, for better understanding the conditions under which creativity and innovation take place.

Two categorical modes are proposed: the incremental view argues that *stimulus responses* are retrieved from memory, whereas the non-incremental view argues that design problems can be solved through rapid cognitive restructuring where creative ideas emerge from an insightful, unconscious and discontinuous context. The research captures events of drastic change and investigates the transformation of ideas associated with the interim products. Such events are hypothesised, reflecting significant transformation in concept reasoning and the configuration of the design product.

This research adopts a mixed methodology. A deductive approach evaluates the predefined protocols that aim to capture the series of design events, while an inductive approach collects data and ethnographic observations for the empirical study of architectural design experiments. A joint descriptive approach of *quantitative* and *qualitative* analyses is developed to detect the role of evolving actions and structural units of reasoning, particularly the occurrence of creative insights ('eureka' and 'aha!' moments) in the formation of concepts by judging the gradual transformation of mental imagery and external representations in the sketching process. Architects with different backgrounds and expertise are invited to participate in this empirical study, which includes 12 pilot studies and 6 primary case studies. Design briefs are categorised into two types: (1) Unstructured brief to design an *Expo Pavilion*; and (2) Structured brief with functional requirements and conditions to design a *Cheese Factory*. Using *linkography* protocols, an objective tool is proposed to acquire information from the design process combining syntactic analysis of *space syntax* theory, *network analysis* and *character strings of information* in a joint framework. Based on the analysis of both categories of design brief the validation and reliability of the proposed descriptive model is examined and verified. The findings of this research are threefold:

First, the empirical study shows that for any design process procedural components are subsets in solving the design problem for synchronic concept development or implementation of the predefined conceptual idea (local scale), whereas contextual components relate to a comprehensive view to solve the design problem through concept synthesis of back- and forelinking between the diachronic stages of the design process (macro scale).

Second, This study introduces a new method of looking at evolving design moves and critical actions by considering the time of emergence in the structure of the reasoning process. Directed linkography compares two different situations: the first is synchronous, looking at relations back to preceding events, and the second is diachronic, looking at the design state after completion. Accordingly, the context behind the emergence of creative insights can be categorised in two ways: there are insights that emerge in incremental reasoning to *reframe the solution* (prevailing concept), and there are sudden

insights (eureka and aha moments) that emerge in non-incremental reasoning to *restructure the design problem* and *reformulate the entire design configuration*. Creative qualities for evolving design actions range between both categories.

Third, two architectural designing styles are identified in the design experiments: some architects define the design problem and concept early in the thinking process, set goals and persevere in framing and reframing this original setting throughout the process to the end, whereas others initiate the concept by designing independent conceptual elements and then proceed to form syntheses for the design configuration. This latter style takes a holistic approach of lateral transformation and divergences. Sudden mental insights are most likely to emerge due to the unexpected combination of synthesis, particularly in the latter style.

This dissertation contributes to current theorising in various ways. The first contribution is methodological: a descriptive method of quantitative and qualitative analyses. The second is the interpretation of creative discovery and associated phenomena in design reasoning. The third is the provision of new insights into the understanding of design thinking and what it means to think and design as an architect. In its contribution to *design research* and *creative cognition* this dissertation paves the way for abetter understanding of the role of reflective practices in design creativity and cognitive processes.

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Glossary

Design Process
The designer's sequence of activities is called a design process, which includes the emergence of insights, evolution and transformation of ideas and formation and development of design concepts.

Design Product
In the technical rationality paradigm, the interim products are seen structuring the design process, acting as *bodies of knowledge* and knowledge is *embodied* in the products of designing. In the epistemology of practice, the emerging products are dependent on the aspect of design situation.

Procedural Components
The parts or subsets of solving the design problem for synchronic concept development or implementation of the conceptual idea (local scale).

Contextual Components
Relate to the whole design problem for concept synthesis of back- and forelinking between the diachronic stages of the design process (macro scale).

Creative Cognition
This is an area of research that investigates human creativity relevant to the cognitive processes taking place in the mind. This area shares principles from cognitive science, psychology and brain studies (where some studies rely on functional magnetic resonance imaging fMRI technology) in order to understand how people think and what could be happening while thinking of a creative idea.

Design Cognition
This is an area of research that investigates the cognitive processes taking place in the mind while designing. There are plenty of models that aim tot understand the way architects think and design and particularly to investigate the relationships between the stages of thinking and evolution of thoughts.

Creativity
To come up with unprecedented ideas, which have value of the product's function and novelty. To come up with good quality design ideas.

Design Reasoning
It defines the relation between the *contents* of design (the interim products) and reasoning *structure* (Goldschmidt and Weil, 1998). By *structure*, they meant consistent internal relationships and patterns that could be detected in the cognitive operations involved in design thinking, while by *contents*, they meant the context-bound subject matters that were being considered, such as rooms and walls in the case of architectural design (Goldschmidt and Weil, 1998: 85).

Forms of Reasoning
Two forms of reasoning are identified for investigation: *incremental* and *non-incremental*. The incremental mode is signified through the consistent trajectory of development (reflecting a *structured* thinking process), while the non-incremental mode is signified by investigation, exploration and synthesis (reflecting *spontaneity*, *unpredictability* and *freedom*). Incremental reasoning preserves the original design concept and develops it, whereas non-incremental reasoning reflects the variety of ideas and synthesis.

Modes of Thinking
Psychologists suggest that human beings often use two modes of thinking; the *associative* and the *rational*. The associative system makes use of visual representations when they are relevant (Sloman, 1996), while the rational mode specifies a rule-based system.

Convergent and Divergent Thinking
Divergence is 'thinking that moves in diverging directions to involve a variety of aspects, which might lead to novel ideas and solutions that are associated with creativity', while *convergence* is 'thinking that brings together information focused on solving a problem' (Goldschmidt, 2014: 46).

Structure of Reasoning
The syntax of thinking through the design process – how design actions and ideas relate to each other.

Design Moves (step, action, utterance) – Structural Units of Reasoning
A design 'move' is an action of reasoning; a design 'step' transforms the design situation relative to the state it was in before that move (Goldschmidt, 1990).

Critical Move
Critical moves are key frames in the thinking process that are associated with the novelty of design.

Sudden Mental Insight
It is a *stimulus response* that occurs in the mind suddenly when an unexpected idea is flashed. It coins the phenomenon of *eureka* moment (aha! event) that refers to Archimedes when he found the solution to weight the king's crown and estimate the gold mass. Major views have encapsulated the controversy of interpretation of what is a sudden mental insight. While one viewed design is a *hierarchical* process where the emergence of sudden insights reflects 'incremental' reasoning (Weisberg and Alba, 1981), the other argued that design is a *transformational* process where creative insights result from the reflection-in-action with products. The Gestalt school however, viewed that the emergence of sudden mental insights is the *rapid cognitive restructuring* of design problem, stating that creative insights are subject to breakthroughs (Metcalfe and Weiße, 1987). Akin and Akin (1996) denoted that a sudden mental insight occurs to break out a frame of reference and shifts the design intention to a new one when a fixation effect is experienced causing blockage while solving the problem and generating the solution.

Creative Leap
Creativity is often characterised in the design thinking process by the occurrence of a significant event – the so-called *creative leap*. This term was first proposed by Cross (1997) to indicate the effectiveness of creative insights on fostering the solution to overcome an experienced problem. The occurrence of sudden mental insights by which novel solutions become possible is considered a 'situation-based' event (Akin and Akin, 1996).

Cognitive Action
The term is proposed by Suwa and Tversky (1997), Suwa et al. (1998) in the macroscopic cognitive scheme to represent four categories of actions that refer to different mental processes: physical, perceptual, functional, and conceptual actions.

Wallas model
In 1926, Wallas was first to incorporate this view into a general model to elucidate creative problem solving, which consisted of four stages: *preparation*, *incubation*, *illumination* and *verification*. The conceptions for creative leap have been formed accordingly and has

been regarded as central to design creativity ever since.

Bisociation of matrices
The fundamental idea of Koestler's (1964) model of 'bisociation of matrices' is that any creative act is a *bisociation* (not mere association) of two (or more) apparently incompatible frames of thought (Krikmann, 2006). In scientific inquiry for example, the two matrices are fused into a new larger synthesis (Deacon, 2006). The recognition that two previously disconnected matrices are compatible generates the experience of 'eureka'. It was suggested that creative thoughts or breakthroughs are characterised by acts of sudden illumination.

Designer's Idiosyncrasy
This refers to the designer's personal actions and attempts to think and design where he/she may use personal behaviour and skills for designing. The designer's idiosyncrasies can be detected during the execution of the idea through sketching, thinking etc., e.g. rendering the conceptual elements of the idea to emphasise it, mirroring or flipping the design configuration to reconfigure the spatial organisation, zooming in/out, adding details, tracing elements from one drawing to another.

Design Models
Design models are classified into two major groups, the prescriptive models that specifies the sequences of events that occur in the process in a logical order, and the descriptive models that describe the events and identify the implication of the emergent action.

Simonian Positivism School
The technical rationality approach looks at design as *concerned with how things ought to be* (Simon, 1969); design is an incremental, procedural process where the relation between the *contents* (artefacts of design) and *structure* (reasoning process) is *hierarchical*.

Schönian Constructivism School
The *epistemology of practice* of *Schönian constructivism* looks at design as a *reflective conversation with the situation* (Schön, 1983); design is a contextual activity based on environment, and the relation between *contents* and *structure* is *transformational*.

Design as a knowledge-based process
In 1996, Hillier introduced the definition of design as a '*knowledge-based process*', a structured approach where architects act as '*social programmers*'; retrieving ideas from the society to think with.

***Form–Function* relation**
To answer the question '*where do ideas come from?*' Hillier (1996) put forward a proposition on the generic relation between *form* and *function* by which social ideas enter the creative design process as ideas to think with; the *form–function* relation is central to his conception of design as a knowledge-based process.

Space Syntax
In 1984, Hillier and Hanson introduced the theory of space syntax (which describes and explains the role of spatial arrangement on the social interactions of people in built environments, the best known of which is called *space syntax*) and proposed that, in general, the form–function relation in buildings and cities passes through the structural properties of whole configuration and that knowledge of spatial configuration is a key dimension in the design domain of architecture.

Configuration
In space syntax, configuration means not simply relations in a complex, but relations which take into account other relations (Hillier, 1998: 37).

Whole and Parts in Complex Systems
Configuration is a necessary strategy to look at the design process because complexity of relation has two key properties of the whole: first, a complex appears to be different when looked at from different points, and, second, changing a part of a spatial complex is likely to change the structural properties of the whole. Hillier (1998) illustrated different examples of configurations to show that when a part of a spatial complex is changed, the structural properties of the whole are also likely to change.

Intelligibility, Connectivity, Depth and Integration Measures
Intelligibility is the correlation between connectivity and integration, the same correlation value is constituted for any element in this particular system.
Connectivity measure is the number of immediate vertices that are directly connected to the present vertex under the quantification test, providing a local static measure.
Depth measure is the least number of syntactic steps in a graph that are needed to reach one vertex from another. It is the natural metric distance between all pairs of nodes, which is defined by the *length of their shortest paths*. The farness depth for a node is the sum of its distance to all other nodes in the network. High depth reflects a deep structure.
Integration is a static global measure that describes the average depth of the network created for the vertex to all other vertices in the system. The vertices of a system can be ranked from the most integrated to the most segregated.

Relative asymmetry RRA
Relative asymmetry (RA), or *relative depth* can be thought of as the measure of integration. The least depth exists when all vertices are directly connected to the original vertex and the most depth is when all vertices are arranged in *unlinear* sequence away from the original vertex as every additional vertex in the system adds one more level of depth. It is a general measure of integration for the system as a whole. Note that integration is inversely correlated with real asymmetry and mean depth.

Closeness centrality
This is a measure of how long it will take to spread information from a vertex to all other nodes sequentially. It is considered the inverse of the farness depth; the more central a node is, the lower its total distance (depth) from all other nodes.

Betweenness centrality
It quantifies the number of times a node acts as a 'bridge' along the shortest path between two other nodes. It indicates the control of a human on the communication between other humans in a social network (Freeman, 1977). Vertices that are predicted to occur on a randomly chosen shortest path between two randomly chosen vertices have a high betweenness.

Design Creativity and Quality
Creativity is defined by Newell et al. (1963) as equalling Innovation + Utility. The quality of a design action or an emerging artefact can be assessed. Sternberg's (2003) model showed different qualities for creative contribution for the design actions, which are classified into three main categories: preserving the main concept, defying/changing the original concept, and integrating with the original concept.

Transformation of Ideas
There are two types for the transformation of ideas from one state to another that were indicated by Goel (1995):
(1) A *lateral transformation* is one where movement is from one idea to a slightly different idea rather than a

more detailed version of the same idea.
(2) A *vertical transformation* is one where movement is from one idea to a more detailed version of the same idea.

Linkography
Linkography is a graphical representation that captures the structure of events and codes their dependency relations in the design reasoning process. Constructing the network of relations of this protocol appears to be forming patterns and chunks of links. Dense networks are hypothesised as reflecting the stages of *convergent* thinking while sparse networks reflect *divergent* thinking. This is still a matter of investigation during empirical study.

Frame of Reference
A reference of an idea, framing an idea to a particular reference may cause fixation effect.

Eureka (Aha) Event
The sudden illumination of sudden mental insight

Mathematical theory of Communication and Shannon's Entropy
Shannon entropy aims to measure information associated with a communication source. Shannon (1946) suggested that the amount of information carried by a message is based on the probability of its occurrence. In physics, entropy is defined as a measure of the disorder state in the system.

Information
Information is a crude measure that confirms a clear increase in regularity overall, extreme regularity and apparent similarity are likely to deliver a very low probability value.

Information Theory and Entropy Theory
Information and *entropy* are two angles from which to look at linkography. While the information theorist looks at the *probability* that can be created for a sequence of relations for a single *item*, the entropy theorist considers the *set* (which is made up of items) a microstate on its own for the system. The two theories are in opposition. Entropy grows with *probability*, while information increases with *improbability*. The less likely an event is to happen, the more information its occurrence provides. Entropy is a measure of the state of disorder for any system. The aim of estimating entropy in information theory is to predict the probability of an event occurring. The objective of information theory is to investigate probability by establishing the number of possible sequences that can be created per single item. The sequence of an item is not taken into account in entropy theory but is necessary in information theory. Information theory is adopted to develop a quantitative approach to quantify the possible relations that are likely to occur at each item in the linkograph.

Deterministic Information Theory DIT
Titchener first presented the *DI* theory in 1998. A series of developments followed to obtain more accurate computation on *variable-length* strings of codes. This theory presents *t-code sets* to encode the frequently occurring symbols of an information source, in which *messages* from any source can be coded into *alphabets* or *symbols* of *codewords* forming *a character string of information*.

Decoding Linkography
Two coding alphabets can be characterised when coding the dependency relations in the linkograph: '1' for *linked* and '0' for *unlinked*. In this method, the linkograph can be transcribed into an alphabetical string of the two symbols and with a string length of all the relations that can be coded from a node to the others (length = n-1; where n is the system's size; the number of all moves in the linkograph). To code information at each de- sign move, we look at its *preceding* and *following* relations and thus we can extract a character string and inspect its properties. As a rule of thumb, prior to DIT, however, characters cannot be processed directly without forming what is often called in the theory, 'codewords'.
DIT proposes a set of codes where each code measures a parameter on the character string of information. Titchener developed this theory in stages (1998, 2004). T-code sets comprise two primary algorithms: t-decomposition decomposes the complexity of the character string into its possible primary level; in contrast, t-augmentation augments the primary units' 'codewords' to reproduce the full character string. By using this theory we can compute the t-code measures such as t-entropy, t-complexity and t-information for any string.

T-code Measures
The application of the t-code' string computation method is based on the deterministic information the ory that was developed by Titchener (1998a; 1998b; 1998c; 2004).
In this method, an algorithmic proce ss is applied to sets of information t o compute the string measures, deno ted as 't-complexity' and 't-entropy' (see: Titchener, 2004; Titchener et a l., 2005; Speidel et al., 2006; Speide l, 2008). The string signifies various types of information encoded into s ymbols. If the string comprises a rep eating sequence of one symbol only (one attribute), then entropy decline s to zero value and the complexity st ructure of the string gets lower, e.g. OOOOOOOOOOOOO, but if a stri ng is composed of two or more sym bols then the probability of appearan ce gets higher, e.g. LROoRRoRLOo LLLORLOooOoR. This means the complexity of string increases accor ding to the size of the symbols and t he composition. The size of string is a crucial factor since longer strings give more accurate measurements th an short ones. The complexity of stri ng depends on the number of produc tion steps that are required to constr uct this string (Titchener, 2004).

Complexity
The complexity of the structure of reasoning of the design process is multi-levelled.

Kolmogorov complexity
In 1963, Kolmogorov derived a measure that complexity of an object, such as a piece of text, is a measure of the computability resources needed to specify the object. It is the minimum steps required for the construction of a piece of text (also known as: string of characters).

Order, Structure, and Disorder
Segregation or *integration* of networks varies from case to case: the pat- tern is sometimes coherent and parts are connected despite the diversity of the cognitive activities undertaken, but this cannot be postulated as a general rule because sometimes a total separation occurs between two or more subsets. Based on this, the structure of linkograph varies between *fully connected and saturated* or *totally random and disordered*. Both are extreme situations in design thinking. Thus three prototypes of linkographic patterns are categorised: *highly ordered*, *structured* and *disordered*, reflecting *integration*, *coherence* and *diversification* respectively.

Pattern-Matching Factor for Linkography
The application of classical entropy to quantify linkograph has been argued. To rectify the estimation process of Shannon entropy, his method adjusts entropy value with a *pattern–matching* factor to pick up the frequency of appearance of patterns into the estimation.

Chapter

1 An Introduction to the Research Problem, Questions and Goals of the Study

Architecture is a *man-made cultural artefact* associated with *creative discovery* and *innovation*, where design research focuses on understanding the nature of design processes and associated phenomena. *Design cognition* is one of the important themes that is concerned with understanding the role of 'knowledge of practice' and 'cognitive activities' in *design reasoning*. In the design *cognitive process*, the architect attempts to develop a strategy to formulate the *problem* (subject of design) and propose *apposite solutions* in order to transform the design state from *ill-defined and unspecified* to *well-defined.* A variety of strategies are debated in design studies. One eminent strategy among designers is to analyse the problem, create syntheses of ideas and evaluate the emerging products to achieve the best possible solutions for the set of objectives and functional requirements. However, it is most likely the architect will reinterpret the programme of requirements (set in the *design brief*) to address any newly evolving needs for the recipient community (usually the client). We argue that to be able to claim that design has novelty, it has to add unprecedented value to the recipient community; the creative architect (designer or planner) is the one who always searches for elements of 'renewal' and 'innovation' that consider the emerging needs for the recipient community during the search for the best solution.

Defining 'what design is about' is an ongoing debate in the field of design research. Design is interpreted according to a variety of views, but two particular views formulate the debate: one argues for a technical rational view where design is defined as *concerned with how things ought to be*, targeting the process of *making* in the *positivist* and *Simonian* view (Simon, 1969), whereas the latter looks at the actual practice, defining design as *reflective conversation with the situation* in the *community of practice constructivist* and *Schönian* view (Schön, 1983). Others, such as the *structuralists*, suggest that design is a *hierarchical* process, where ideas are likely to evolve in a 'top-down' way; the emergent products are outcomes of a structured thinking process and design decisions are probably 'process-oriented'. On the other side, the *constructivists* argue that design is rather a *transformational* process, where 'good' design ideas emerge from the 'reflection-in-action' on the interim artefacts of mental representations; *unexpected discovery* evolves in the *situation* of practice and design decisions are likely 'action-centric'. There is also the *algorithmic* view that defines design as a *procedural* process, where each action is visited only once in a linear thinking process. Hence, a controversy about the nature of design processes and creative discovery has arisen.

The boundaries between these views are not clear cut; the views are intertwined in some areas. The problem lies in the way in which the design process is reviewed and interpreted, which reflects the researcher's tendency to capture the role of certain components and disregard others that may cause a confounding effect while investigating certain phenomena. For example, scientific progress during the 1960s and subsequent attempts to understand the 'human mind' and more about 'nature' and the theory of 'origin and evolution', as well as the implementation of computers and the digital revolution in media and industry, have influenced researchers to develop technical approaches to reinterpret and improve design processes, which seemed to be automation or mechanism to some extent. Perhaps the most influential of the models in the 1960s is that of Christopher Alexander (1964) who put forward a technical design method; a system that maps *functions* on *forms*, for example, an Indian village. This particular model significantly influenced design researchers for many years until Alexander retracted his ideas in 1971.

There have been also great attempts to interpret 'human creativity' for 'artificial intelligence' in this field of research. While each proposition stems from a particular paradigm, revealing the theory beyond each model is crucial to understand how creative discovery and nature of design process has been looked at. Dorst and Dijkhuis (1995) classified the paradigms of research and endeavours beyond the proposition of design models into two major stages. The first is *technical rationality*, which prescribed design as a cyclic process, through which designers have to pass periodic intrinsic stages to formulate the problem and generate and evaluate the solutions, switching between *analysis*, *concept generation*, *synthesis creation* and *evaluation* stages. Examples of this type of 'process-oriented' model are: 'conjecture–refutation' (Popper, 1963); 'synthesis of form' (Alexander, 1964); 'generate–test' (Simon, 1969); 'conjecture configuration-test-refutation' (Hillier, et al., 1972,); and 'analysis, synthesis, and evaluation' (Jones, 1963), and other models. The latter is the *reflection-in-action* paradigm, which describes the *situated action* of design by adopting the *epistemology of practice* view. It considers the design process is one of 'co-evolution of the design and the brief with the one stimulating the other iteratively. At the end of the design process, one should have developed both a design and a relatively well-stated brief' (Penn, 2008). It considers also that the aspect of 'design situation' is central to understanding the reflective practice with the emerging representations and artefacts in the reasoning process for the evolution of ideas. Examples of this type of 'action-centric' models are: the 'perceived situated errors and corrections' model of learning (Argyris and Schön, 1978); 'reflective practice' or 'reflection-in-action' (Schön, 1983); 'situated transformation of information into knowledge' (Kolb, 1984); 'structured reflective practice' (Gibbs, 1998; Johns, 1995); and interpretations of the 'reflection-in-action' theory (Brookfield, 1998; Rolfe, et al. 2001).

This multiplicity of views trying to understand 'what design is about', may imply certain directions of research in the field that may confound the researcher while investigating the inference of certain phenomena if he or she is not aware of these views.[1] The paradigm shift between the Simonian and Schönian views is a clear example to identify the paradox in design research. Rittel and Webber (1973) clearly identified that architectural design and planning problems are 'ill-defined' and 'wicked'. Architecture design requires the architect to formulate the problem, and perhaps reformulate it through the process again (if new dimensions are explored); identifying the problem may evolve with the generation of ideas and solutions when knowledge moves from *tacit* to *explicit* state (Penn, 2008). In other domains of design, e.g. engineering and industrial design, the problems are 'well-defined' – specified with clear information and goals in advance of the process. Another crucial issue that distinguishes architecture and planning is that designers vary in their ways of interpreting the aspects they regard as the most important as focal points in the design problem and most likely sources of creativity for concept design. A good example is given by Lawson (1979a, 1979b), who found that architecture students tend to adopt a 'solution-focused' strategy when solving a problem, while science and engineering students tend to adopt a more 'problem-focused' strategy. Because all the necessary information is not available for *ill-defined* problems they cannot be subjected to the extensive analysis that *well-defined problems* receive state, and Cross (1982: 224) pointed out that 'a solution-focused strategy is clearly preferable to a problem-focused one; it will always be possible to go on analysing "the problem", but the designer's task is to produce "the solution"'.

In this research study, two views in this debate are identified for investigation: first, the phenomenon of the emergence of 'sudden mental insights' and their role in the structure of reasoning, and, second, the relation between the *contents* (artefacts of design) and *structure* (reasoning process). Major views have encapsulated the controversy of interpretation. For example, concerning the creative insights, while one viewed design as a *hierarchical* process where the emergence of sudden insights reflects 'incremental' reasoning (Weisberg and Alba, 1981), another argued that design is a *transformational* process where creative insights result from the reflection-in-action with products and are subject to breakthroughs (Metcalfe and Weiße, 1987). The Gestalt school however, viewed the emergence of sudden mental insights as the *rapid cognitive restructuring* of the design problem.

In this study, we aim to find *empirical evidence* of the nature of creative discovery and design processes, debate the reliability and validation of those views, and draw conclusions from the findings of real architectural design processes through ethnographic observations. A group of various architects were invited to participate in this empirical study. The protocols and cognitive activities of the architects were recorded to identify the evolving actions, capture the structural units of reasoning and the synthesis processes. We adopted a mixed research methodology of *deductive* and *inductive* approaches for investigating the design processes. An integrative analytical framework of quantitative and qualitative methods was developed to identify the evolution of moves, actions and creative insights ('eureka' and 'aha!' moments) that were taking place in the design process using *linkography* protocols. Predefined segmentation and coding protocols were probed to examine the structure of events and *dependency* relations among the series of design episodes, where each action may have relations with the *precedents* and *subsequent* events.

[1] Definitions and ideas about the nature of 'what design is about', 'process' versus 'product', and strategies for 'problem formulation' and 'solution generation' predominantly revolve around the Simonian versus Schönian view. Waves of design thinking and definitions of design are presented in detail in Appendix 1.1.

There has been great interest in the use of linkography to describe the events that take place in design processes with the aim of understanding when creativity takes place and the conditions under which creative moments emerge in the design. It is a graphical representation that captures the structure of events taking place in the design process. It is also a directed graph network and because of this it gives resemblance to the types of large complex graphs that are used in the space syntax community to describe urban systems. In this research, we investigate the applications of certain measures that come from space syntax analyses of urban graphs to look at linkography networks. One hypothesis is that complexity is created in different scales in the graph system from the local sub-graph to the whole system. The method of analysis illustrates the underlying state of any system. Integration, complexity and entropy values are measured at each individual node in the system to arrive at a better understanding on the rules that frame the relationships between the parts and the whole.

This is relevant to our proposition for a coding scheme. While predefined segmentation and coding schemes are examined, our aim is to develop a coding scheme that captures the gradual transformation of concepts of 'mental imagery' during the reasoning and sketching processes. Quantitative and qualitative methods are deployed to judge the 'transformation' versus 'drastic change' between pairwise emerging products and the overall reasoning structure (i.e. sketches, any external representations of design artefacts and final products). We aim to propose an objective tool to acquire information from linkography, which combines syntactic analysis of *space syntax* theory, *network analysis* and *information* measurements in a joint framework, and to detect the evolution of creative ideas and formation of novel concepts for investigating creative discovery and associated phenomena.

1.1 Research Question and Problem Definition

Our objective is to find out how design is best described. This research hypothesises that design processes comprise *procedural* and *contextual* components, and the question we aim to answer is: *What role do procedural activities* (where each design step reflects a unit in a linear process) *and contextual activities* (an action based on the situation, environment and affordances) *play in the generation of creative insights, critical moves, and the formation of design concepts in the reasoning process?* By identifying these components we aim to understand the design process and particularly the context behind the emergence of creative insights and formation of design concepts. In the empirical study, creative discovery is investigated in structured and unstructured design briefs so as to assure the reliability and validation of the research outcomes. In the following, two problematic points are highlighted for investigation: the best way to describe creative discovery and emergent phenomena and the relation between *contents* and *structure*.

1.1.1 Creative Discovery and Emergent Phenomena

Creativity is often characterised in the design thinking process by the occurrence of a significant event – the so-called *creative leap*. This term was first proposed by Cross (1997a) to indicate the effectiveness of creative insights on fostering the solution to overcome an experienced problem. The occurrence of sudden mental insights by which novel solutions become possible is considered a 'situation-based' event (Akin and Akin, 1996). The story of the 'eureka' or 'aha!' moment for Archimedes revealed that creative insight occurs after a 'mental block' or 'impasse' while solving the problem (Akin and Akin, 1996; Chiang, 2006).[2] Designers often enjoy this mysterious event but do not understand how or why it occurs. While there have been some attempts to capture and reveal the context of emergence behind this phenomenon, its role in design reasoning and formation of concepts has been rarely investigated in this field of research.

In some views, it is characterised as a sudden perception of a completely new perspective on the situation as previously understood. This was the basis for Koestler's (1964) model of 'bisociation of matrices', where his fundamental idea is that any creative act is a *bisociation* (not mere association) of two (or more) apparently incompatible frames of thought (Krikmann, 2006). In scientific inquiry for example, the two matrices are fused into a new larger synthesis (Deacon, 2006). The recognition that two previously disconnected matrices are compatible generates the experience of 'eureka'. It was suggested that creative thoughts or breakthroughs are characterised by acts of sudden illumination (see Figure 1.1).

[2] A note on the story of 'eureka' for Archimedes, design novelty and authorship is included in Appendix 1.2.

Earlier, in 1926, Wallas was first to incorporate this view into a general model to elucidate creative problem-solving, which consisted of four stages: *preparation*, *incubation*, *illumination* and *verification*. The conceptions of the creative leap have been formed accordingly and it has been regarded as central to design creativity ever since.

While a creative leap may not be a required feature of routine design, it must surely be a feature of non-routine creative design, Archer claimed (1965). Some would argue, however, that any design action, by its nature, is creative to some extent, and it is not necessary to relate the creative leap and the sudden emergence of 'eureka' and 'aha!' moments. Creative design in this case is related to *process-creativity* (Cross, 2007a). This conception is consolidated by the rates and qualities of the creative contribution, which identify the role any design action could be taking in the thinking process; see, for example, Sternberg's model of the 'propulsion theory of creative contribution' (Sternberg, 1999, 2003). Another view states that there are exceptional events when a certain novel, unprecedented idea is generated and can be reliably assessed, at least by peer-groups (Amabile, 1982; Christiaans, 1992). This view suggests that creative design is related to *product-creativity* (Cross, 2007a).

Some others debate that the creative leap might not be an expected displacement of the solution space, but merely a shift to a new part of the solution space that leads to the appropriate solution. It characterises that creative design is about *exploration* rather than *search*. Unlike bisociation, creative design is not necessarily the making of a sudden contrary proposal, but is the making of an 'apposite' proposal. Once the proposal is made, it is seen to be an apposite response to the given, and explored, problem situation. Creative design is therefore regarded as the apposite proposal of a concept that adds value, which embodies novel features for a new design product (Cross, 2007a). Such a proposal may or may not arise as a sudden 'flash of insight', but it will constitute a creative leap across the gap between the functional design requirements and the formal design structure of a potential new product. Cross (2007a) debated that the creative act appears to be not so much taking a leap as building a bridge between problem requirements and solution proposal.

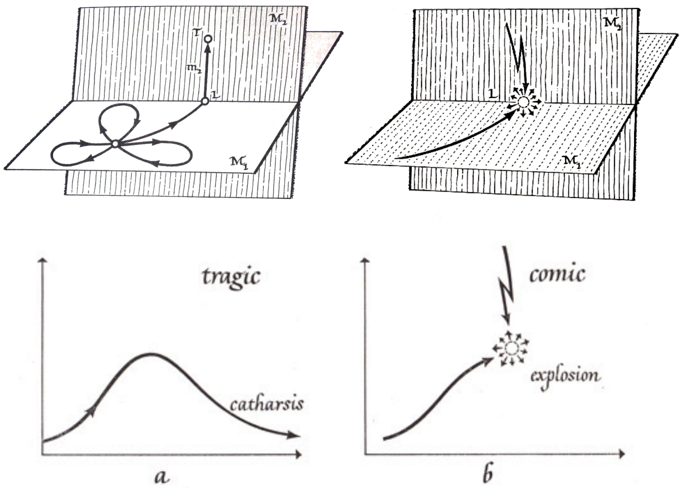

Figure 1.1 Koestler's model of *bisociation* (1964)

A variety of definitions have been proposed to identify the 'creative leap' or 'sudden creative insight' in different perspectives. The phenomenon was addressed in several previous studies as; for example, Schön's definition of the 'invention and evolution of ideas' (1963) as 'treating the new in terms of the old', 'a displacement of ideas from the old situation to new one'; Köestler's conception of the 'bisociation of matrices for the creative act' (1964) as operating on more than one plane – the former may be called 'single-minded' and the latter 'double-minded' – presenting the transitory state of unstable equilibrium where the balance of emotions and thoughts is disturbed; Akin and Akin's identification of 'sudden mental insight' (1996) as 'any sign on perceiving a notion to break out a frame of reference and shift to a new one'; Csikszentmihalyi's definition of the 'creative process' (1996) as 'flow and the psychology of discovery and invention'; and Johnson's conception of a 'good idea' (2010) as two thoughts colliding, one that has incubated for a long time in the mind with another arising from the present situation.

Two main opinions formed this debate on the nature of creative insights around which research efforts are clustered. According to one position, creative discovery is systematic and organised and is based on highly structured processes (Perkins, 1981; Ward, 1994; Weisberg, 1986). According to the other, *randomness* and *chance* play a vital role in creativity, leading to novel variations in thinking and syntheses processes (Bateson, 1979; Findlay and Lumsden, 1988; Johnson-Laird, 1988).

The former opinion affirmed that insights are *retrieval* from memory, acting as 'stimulus responses' to a problem with an endorsed structured method of *trial-and-error* in order to develop a creative solution (Schön, 1963; Weisberg, 1986). The latter opinion stated that sudden insights result from rapid cognitive *restructuring* process of the design problem that distinguishes the problem-solving process in terms of a series of insightful processes; once an insight is perceived and realised, the problem-solver can quickly implement its solution (the Gestalt view). A controversy has arisen between the two views, specifically enquiring: how would an insight help to solve the problem? In their explanation, Finke et al. (1992) pointed at two positions:

The *memory* position states that an 'incremental' approach is the way to retrieve good ideas. Thus, insights are structured in the design process (Weisberg and Alba, 1981).

The *restructuring* position states that an 'unconscious' way of thinking acts beyond our awareness where the design problem is to be restructured along the design process. Thus, sudden breakthroughs occur unconsciously and discontinuously (Metcalfe, 1986a, 1986b; Metcalfe and Weiße, 1987). Each school is introduced in Figure 1.2 and the Gestalt view is outlined in Figure 1.3.

Investigating both views in this empirical study aims to elicit the semantics of the cognitive context in which creative insights are generated. Two forms of reasoning are identified for investigation here: *incremental* and *non-incremental*. The incremental mode is signified through the consistent trajectory of development (reflecting a *structured* thinking process), while the non-incremental mode is signified by investigation, exploration and synthesis (reflecting *spontaneity*, *unpredictability* and *freedom*). Sudden mental insights are hypothesised as occurring in the event of reformulating the design brief, and/or restructuring the entire design problem (Chiang, 2006). It was also debated that *unexpected discovery* and *discontinuity* of ideas are a driving force for *creative discovery* (Weisberg, 1993). All these phenomena are of 'creative cognition' and are matters of investigation in this study.

Finke et al. (1992) and Ward et al. (1999), however, introduced an interesting study on *structured imagination*, in which the argument on sudden mental insights was framed while posing the question: 'are creative insights normally derived from existing cognitive structures and representations, or are they chanced upon arbitrarily?' (Ward et al., 1999: 208). While explaining the creative cognition approach, the point was clearly made that 'creative discovery' is not a type of 'either/or' question. Rather, an emphasis should be put on the methods that permit one to determine the relative roles that 'randomness' and 'structure' play in creative discovery.

In another view, it was debated that thinking modes play an imperative rule in the emergence of creative insights. In psychology, it was proposed that human beings often use two modes of thinking; the *associative* and the *rational*. The associative system makes use of visual representations when they are relevant (Sloman, 1996), while the rational mode specifies a rule-based system. Gabora (2010: 2-3, cited in Goldschmidt, 2014) identified 'associative' thought and 'analytic' thought; the former tends to produce intuitive thinking that is 'conducive to unearthing subtle associations between items that share features or are correlated but not necessarily causally related'. This 'may lead to a promising idea or solution, although perhaps in a vague, unpolished form' (ibid.). In contrast, 'analytic thought is rule-based and convergent', and is 'conducive to analysing the relations of cause and effect between items are already believed to be related' (ibid). These descriptions correspond to the terms *divergent* thought and *convergent* thought that are widely used by creativity researchers. *Divergence* is 'thinking that moves in diverging directions to involve a variety of aspects, which might lead to novel ideas and solutions that are associated with creativity', while *convergence* is 'thinking that brings together information focused on solving a problem' (Goldschmidt, 2014: 46). Thus, inspecting venues of convergence and divergence in the design cognitive process is supposed to characterise the role of sudden mental insights and the relation to the emergent artefacts.

Recent publications investigating the sudden mental insight phenomenon can be divided into two groups. The first group reflects efforts to develop quantitative methods to indicate the 'surprising' moments using protocol methods. Kan and Gero (2005a, 2005b, 2008, 2009a, 2009b, 2010, 2011), Kan et al. (2006, 2007), Gero et al. (2011), Pourmohamadi and Gero (2011) presented serious attempts to detect the emergence of sudden mental insights using linkography and Shannon's entropy of the mathematical theory of information. One of the objectives of this research is to examine whether the quantitative methods are able to fully detect this phenomenon of creative cognition and they are therefore investigated further. The second group deduces the creative discovery and associated phenomena theoretically, e.g. 'how good ideas evolve' (Johnson, 2010), or 'changing education paradigms' (Robinson, 2010). Some other attempts adopted 'functional magnetic resonance imaging' (fMRI) technology to scan the human brain during the processing of cognitive activities, e.g. 'exploring the neurological basis of design cognition using brain imaging' – how the cortex functions during the decision-making process (Alexiou et al., 2009), or 'functional modularity of semantic memory revealed by event-related brain potentials' – the effect of fixation and the sudden occurrence of eureka insight (Kounios, 2007).[3]

[3] Experiments to use fMRI technology to identify the cognitive state of the mind while passing a fixation effect or before the emergence of sudden insight are included in Appendix 1.3.

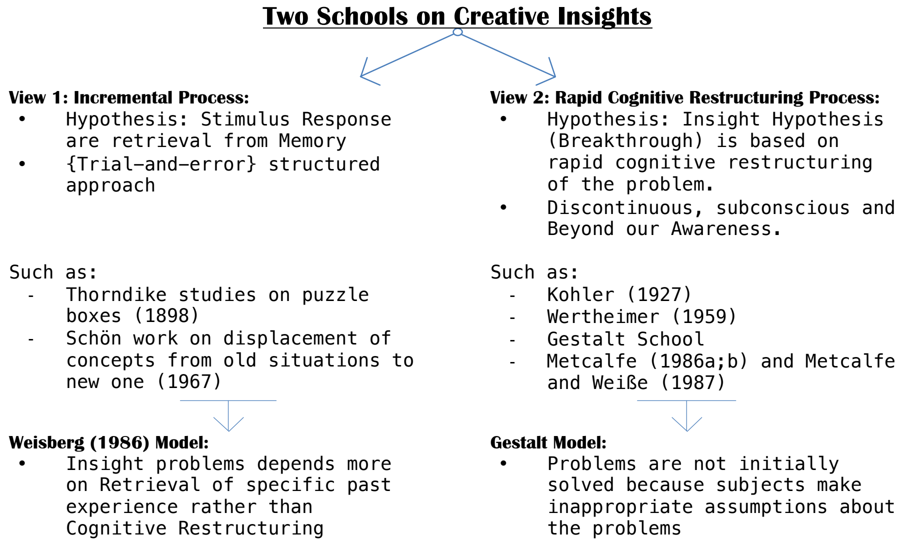

Figure 1.2 Two schools debate the role of sudden mental insights

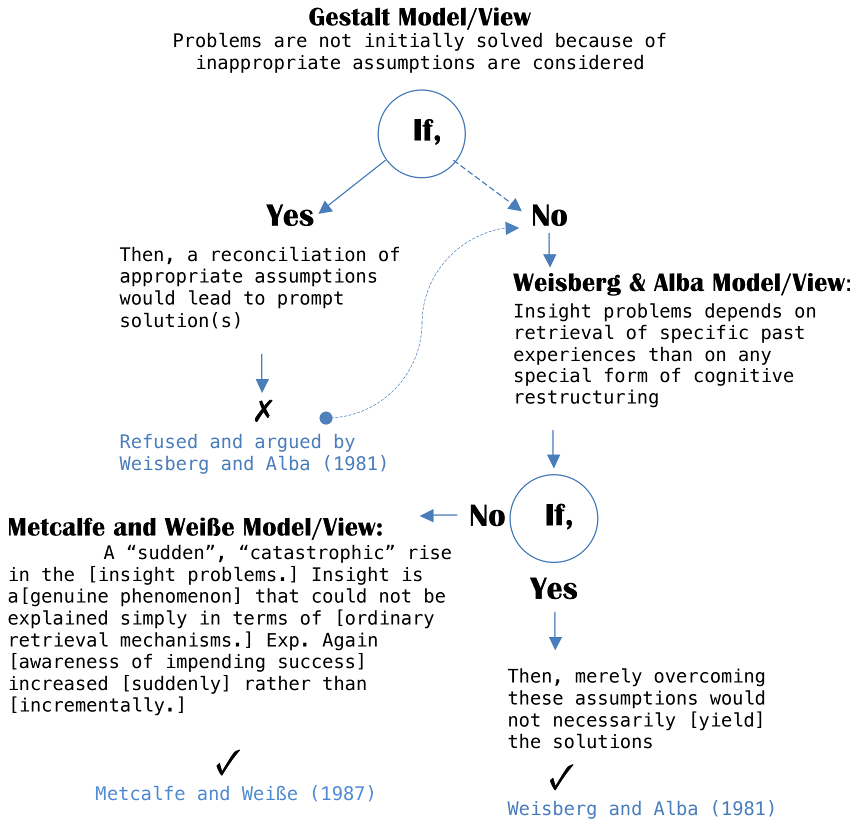

Figure 1.3 The Gestalt model to interpret the sudden emergence of mental insights

1.1.2 Contents and Structure in the Reasoning Process

Another problematic point for investigation in this debate is the relation between the *contents* and the *structure of reasoning*. One hypothesis put forward by the *structuralists* in the 1970s supported the argument that interpreting this relation is necessary to understand the nature of the structure of thinking. Piaget (1971) conceived that the relation is *hierarchical* in his model and proposed integration to render the relation between the 'content' and 'structure of form' as a *pyramidal* type of thinking, i.e. to move from step '1' to step '3', you must pass via step '2'. Following this model, creative insights were considered to be outcomes of an *incremental* reasoning process. Piaget's model was dedicated to the discovery and explication of structure in thought and matter. He was very aware of the complex relationship between structure – often equated with 'form' in his writings – and contents.

Another hypothesis was formulated in Goldschmidt and Weil's study (1998). In contrast to the views of Piaget and other structuralists, they distinguished the relation between the 'contents' and 'structure of form' as *transformational* and not hierarchical. By *structure*, they meant consistent internal relationships and patterns that could be detected in the cognitive operations involved in design thinking, while by *contents*, they meant the context-bound subject matters that were being considered, such as rooms and walls in the case of architectural design (Goldschmidt and Weil, 1998: 85). They further argued that *structuralism* already endeavoured to reintegrate content with form whereas Piaget's version of this proposed integration theorised that the relation was nested hierarchically: 'Each element being "content" relative to some prior element and "form" for some posterior element' (Piaget, 1971).

However, Goldschmidt and Weil argued that in reasoning the relationship between the two is not hierarchical; rather, contents and structure concurrently describe the state of a system at any given point and, in effective reasoning, they are apparently extremely well coordinated. In their opinion, this notion assumes a transformational relationship between structure and contents (Goldschmidt and Weil, 1998: 100). This means that at any stage in the design process, at any point of the system, contents and structure synchronously describe the state of design, and the complexity of relations in this case is assumed to be semantic. According to their view, no circular or causal relationships between structure and contents exist. As yet, no attention was given by either side to the sudden occurrence of insight that causes a drastic shift in the design situation.

> Because 'contents' is determined by common sense, intricate backlinks and forelinks may be expected at what may be called a 'semantic level': it is sufficient for any common element to be present in two moves to potentially establish a link among them. Therefore, a move's category/link-direction relationship is by no means obvious. In addition, the correlation we have established results from contents and structure analyses that are perpendicular to one another and, therefore, no circular or causal relationships exist between structure and contents as defined here' (Goldschmidt and Weil, 1998: 99).

However, the relation between 'content' and 'structure' can be considered as the relation between *context of designing* and *recurring patterns of cognitive processes* occurring in the mind at a certain point during the design process. The designer who has a vision to extend the concept of the present interim product is able to demonstrate the relation between the content and structure of reasoning in advance. This vision might then be extended to predict different trajectories to move the interim stage on, necessary for an *on-going* decision-making action. However, this is not always the norm in the architectural design thinking process. The vision for future conceptual development in the design process could differ from one state to another, and from one architect to another.

The design process is subject to the time of emergence of cognitive actions and design moves. We hypothesise that the sudden occurrence of creative insight that shifts the design concept drastically is an aspect of the hierarchical relation existing between the contents and the structure. The design process is transformational when the concept is developed mutually during the reflection-in-action with the artefacts. However, the sudden shift occurs when there is an unexpected discovery that reformulates the entire components of the interim situation to a different design configuration, probably due to an unexpected condition, which structures the following designing actions and the reasoning accordingly. Goldschmidt and Weil's postulation of the transformational relation between content and structure cannot be generalised on this particular occasion. Their interpretation stems directly from the adoption of the *reflective-in-action* model (Schön, 1983) – the reflective conversation with the situation where the designer sees things once reflected from the external representation and develops the concept based on a mutual relation between the *mind* and the *drawing episodes*.

Goldschmidt has extended this concept further by proposing a definition to introduce the design 'move' as an action of reasoning; a design 'step' transforms the design situation relative to the state it was in before that move (Goldschmidt, 1990, 1991). In 1991, Goldschmidt proposed a model for the 'dialects of sketching' where the primacy of *reflective practice* holds for two types of reflective sketching: type (1) aims to transform imagery into new forms of combination and is considered a rational mode of reasoning;

type (2) is sketching to generate new imagery of forms in the mind and is a non-rational form of design thinking (Goldschmidt, 1991; Goldschmidt and Weil, 1998). Revealing the relation between contents and structure in both types of reasoning is crucial for identifying the design segments and eureka moments in the design process and reflection-in-action. Further, this identification is requisite to understanding the context beyond the formation of novel concepts in the design process, and the role of interim products in the reasoning process. If this relation between the contents and structure of reasoning is often transformational, as Goldschmidt and Weil stated, then we are inclined to prescribe every single design process as *incremental*. According to this postulation, conceptual ideas develop in a consistent structured manner and the cognitive style of the designer is often recurrent regardless of the type of design problem, specified functional programme or structured design brief.

In another view, we find Hillier's principles on architecture design (1996, 1998) are crucially dealing with the structure of the design process. Hillier's model stems from the rational paradigm of the 1960s and is based on the *structuralism* school, echoing the logical approach of reasoning of Popper (1963) and Simon (1969). In 1996, Hillier introduced the definition of design as a '*knowledge-based process*', where architects act as '*social programmers*'; retrieving ideas from the society to think with. To answer the question '*where do ideas come from?*' he put forward a proposition on the generic relation between *form* and *function* by which social ideas enter the creative design process as ideas to think with; the *form–function* relation is central to his conception of design as a knowledge-based process. Earlier, in 1984, Hillier and Hanson introduced the theory of space syntax (which describes and explains the role of spatial arrangement on the social interactions of people in built environments, the best known of which is called *space syntax*[4]) and proposed that, in general, the form–function relation in buildings and cities passes through the structural properties of whole configuration and that knowledge of spatial configuration is a key dimension in the design domain of architecture.[5]

Configuration is a necessary strategy to look at the design process because complexity of relation has two key properties of the whole: first, a complex appears to be different when looked at from different points, and, second, changing a part of a spatial complex is likely to change the structural properties of the whole. Hillier (1998) illustrated different examples of configurations to show that when a part of a spatial complex is changed, the structural properties of the whole are also likely to change (Hillier, 1998: 37-38; and see Figure 1.4. The other proposition that is pertinent to this *form–function* relation is about creative activity. Hillier proposed that the transmission of socially programmed ideas into the design process is in most cases *unconscious* and that configuration is consequently *non-discursive*. The difficulty we face in understanding the configurational aspects of social phenomena, e.g. architecture design, perhaps reflects the fact that the human mind deals with configuration without conscious attention. Spatial design is configurational and non-discursive, and non-discursive reasoning is probably what we call intuition (Hillier, 1998: 39).

Space syntax theory states, therefore, the primacy of intuition in architecture design. Hillier advanced this proposition by stating that the primacy of intuition holds only for the phases of design in which design 'conjectures' are generated; the process of testing those conjectures is a *discursive process* involving reasoning, and thus architectural design can be characterised as the *reasoned deployment of intuition*; *design is the rational deployment of intuition* (Hillier, 1996, 1998). According to Hillier, a spatial design is a system of configurational differences that relate to function. A characteristic of configuration is that changing one part means that the whole configuration is changed accordingly. This concept, however, neglects any revolutionary role the sudden occurrence of eureka insight could be causing to change the characteristics of the entire system. On this point, we aim to represent the structure of reasoning in the design process in terms of a linkography system that consists of nodes and links of relations, which resemble the design actions and the dependency relations between them in the thinking process. This point is vital to embarking on our investigation on the effect of sudden insights on the evolution of ideas in reasoning process. It will offer profound insights to consider Hillier's (1998) question: Is design a 'top-down' or 'bottom-up' process?, which is associated with the pertinent point of this research into 'structure of design process'. If the relation of one design action to the rest in the linkography system changes between the synchronous state of emergence to the completion state (after

[4] The term 'syntax', taken from linguistics, here refers to the spatial structure of the whole, as opposed to morphology, which looks at the qualities of individual items. Using this theory, we can analyse existing spatial configurations and in a way measure their socio-spatial performance (Schaffranek and Nourian, 2014).

[5] 'Configuration, in the sense in which it is used in space syntax, means not simply relations in a complex, but relations which take into account other relations' (Hillier, 1998: 37).

the end of the design process), an indication that a critical event is taking place must be examined in relation to the context of the externalised design products. Therefore, a new objective tool to test linkography networks must be developed to investigate the effect of the phenomenon.

Because design is formulated according to the structure of the *parts* and the configuration of the *whole*, we therefore claim the importance of developing a protocol analysis tool in order to look at the design actions during emergence and after completion of the designing process. The aim is to create a better chance of comprehending the factors that affect the formation of novel concepts in design processes. However, it should be noted that Hillier (1998) argues that designers cannot deal fully with the form–function relation unless they have a notion at the level of the whole configuration, or at least in its essentials, which urges our research to consider his argument while testing the design cases. He states that spatial design is likely to be a 'top-down' process and that the configuration is a central aspect of the design product because it may structure the whole process.

> A solution cannot be evolved bottom up from the parts, because how the parts fit together is the critical factor, and the addition of a new part at any stage may change the structural characteristics of the whole. The form–function relation … is emergent at the top level (Hillier, 1998: 40).

Design is a multilevel complex system. To arrive at a better understanding of the rules framing complex relations in the design process, this study seeks to find out whether any rule exists in the complex world: is there a clear order for the structure of a complex system to be easily grasped, or is it actually just random or chaotic and there are no rules in the complex world? The paradox occurs in the second case: if it is truly random, is there a simple way to describe it? Can a complex world be reduced to a single aspect or phenomenon? These questions are discussed throughout the dissertation and are pertinent to the predefined methods that aim to capture the structure of reasoning and quantify the emergence of ideas. Different views are discussed to reveal the role of complexity in structuring the design process and formation of concepts.

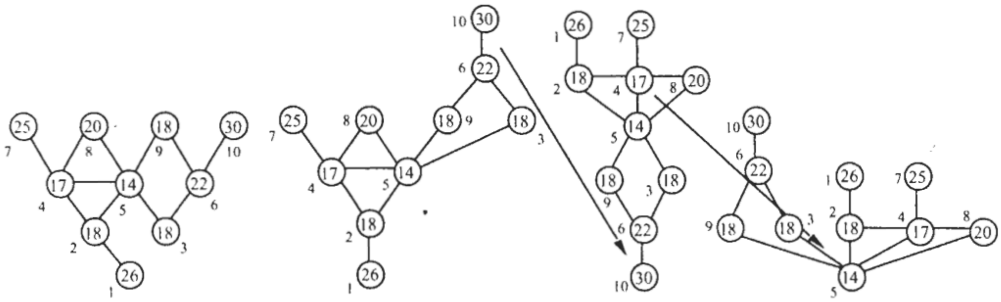

Figure 1.4 Examples of spatial configurations showing the change in the structural property when a part of the spatial complex is changed
Source: Hillier, 1998: 38, a representation for the *justified graphs*.

A key text in this field is Alexander's *Notes on the Synthesis of Form* (1964). Although he later retracted his ideas, in 1964 his theory presented design method as arising from analysis of the problem structure and without a presupposition about the form. Although his intention was to investigate the 'synthesis of form', the study tended to be actually all about the 'analysis of function'; with *form* on one hand and *function* on the other, he attempted to map the function on the form, whereas in designing generally both form and function are imagined, transformed and tested in the process.

What Alexander was trying to capture was not the form, nor the context as such, but the 'structure of places' and ways in which they fail to fit each other. A 'misfit' occurs when the form does not fit the context and in the other way, these misfits are connected to the structure that underlies them. However, this is incoherent because to be specific about whether there is a misfit of the form to the context it is necessary to be specific about what the context is dealing with and what is the form proposed for it. This can be done only when a design proposal is tested in order to see if they fit each other. Alexander misses the idea of the design *goal* in his method and Steadman (2008) argues that this is where the incoherence probably emerges. A design goal guides the designer to search for the apposite strategy to achieve it, and thus Alexander's method misses a crucial part of what the designing process is about. In an interesting study, Steadman (2008: 163-78) presents a critique on the hierarchical structure and the adaptive process based on avoiding the defaults of Alexander's design method.[6]

Although Alexander's objective showed a different proposition, the illustrations he provided in support of the argument (see Figures 1.5 and 1.6) triggered Hillier into rethinking the whole topic by posing the question: *is design a 'top-down' or 'bottom-up' process?* The contribution of this dissertation is about providing empirical evidence on the theories and multiplicity of views on creative discovery and sudden mental insights; we will therefore view this argument through the empirical study and test if design can be both 'top-down' and 'bottom-up' in different design situations.

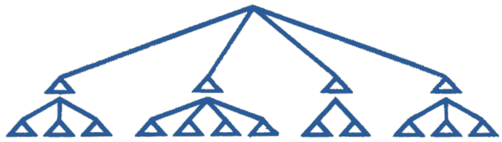

Figure 1.5 Complexity of design process
Source: Alexander, 1964: 151, a representation for the Indian village design.

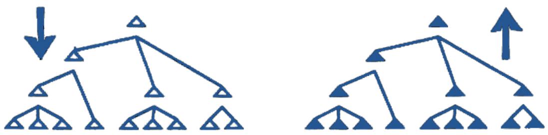

Figure 1.6 Is design a top-down or bottom-up process?
Source: Adapted from Alexander, 1964: 94.

In the following proposals, we identify three general cases on the effect of the generation of innovative ideas on the development of concept in the design process, which could be transformed or changed completely because of exceptional circumstances. In most general cases, the design process begins by generating a variety of ideas at the concept initiation phase; the design decisions are then taken based on the discussions held with the client on the designer's proposals to achieve the brief of functional requirements for the project. One of these proposed concepts is selected, or two or more entities are merged into one idea until reaching something satisfactory for both sides (the client and designer). The final concept is hence executed and any substantial elements are considered in the final production of architectural artefact. Figure 1.7 illustrates the case where a variety of ideas are generated at the concept initiation phase, followed by a series of developments and transformations. This case states that the rate of ideas generated is high at the beginning of the design process and decreases throughout the process until the end.

In other cases that may seem unfamiliar but simulate the real world, the projects are linked to the extent of receiving additional information during the designing process, which has to be taken into account during the development phases. In this case, the designer (design consultancy) thinks of proposals for development but holds on to the original conceptual idea unless significant modifications are introduced to change the entire concept. Figure 1.8 illustrates the peak generation of ideas at the intermediate stages instead of the early concept initiation phase.

In an extreme case, fixation occurs and causes blockage to the thinking process. That requires the designer to think of several options to overcome the problem while the stagnation might be remaining in the designer's mind. Breaking out of the existing *frame of reference* and shifting to a new one is considered the best way to overcome the fixation event, which paves the way for subsequent attempts to be generated to overcome the problem completely. This is conditional on perceiving a *stimulus response* in order to break out of a frame of reference and specify a new one. As a result, a creative insight might occur that shifts the design into another state. Akin and Akin (1996) defined this process as:

[6] 'Hierarchical structure and the adaptive process: Biological analogy in Alexander's *Notes on the Synthesis of Form*' (Steadman, 2008: 163-178). An interview with Professor Steadman on 29 January 2013 is included in Appendix 1.4 in which he elaborates on Alexander's ideas and the rational research paradigm of the 1960s.

> A sudden onset of creative insight, the flash of insight by which a creative idea is frequently reported to occur … An insight coincides with the realisation that the problem can only be solved when a spurious constraint is removed.

In some cases, the designer could think about reformulating the given design programme (brief) to facilitate the emergence of solutions. Figure 1.9 illustrates the disconnection of the original frame of reference causing the fixation to shift to another concept due to a creative insight.

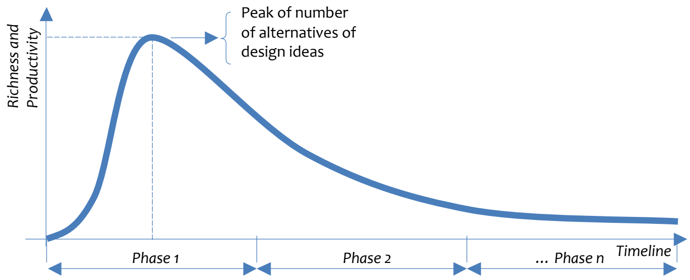

Figure 1.7 A variety of ideas are generated at the initiation phase

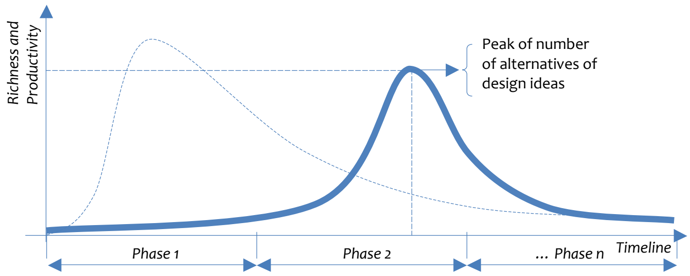

Figure 1.8 The generation of ideas is shifted to the intermediate phase

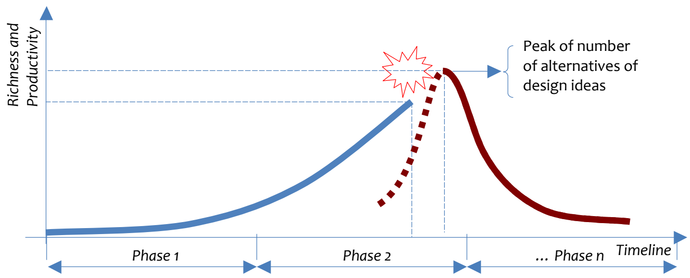

Figure 1.9 The sudden occurrence of mental insight restructures the entire problem and shifts to a new design concept

Akin and Akin's (1996) interpretation appears to hinge on a rational view: design is a structured process with frames of reference; once fixation occurs, a stimulus response might emerge to shift the existing frame of reference to another one. This interpretation states that design novelty and creative insights are not chanced upon arbitrarily. Relevant to Akin and Akin's interpretation was Schön's (1963) claim that concepts are displaced from the 'old' to the 'new' situation – treating the new as old is an extension of the old. A process of 'transposition' is complicated by the fact that there are no isolated concepts in ordinary thought but concept clusters. Both views fall under the rubric of theories of *reduction*, where novelty and emergence are treated as the 'recombination of old ideas'; what is known as *associationism* in the theories of *reduction*. According to the associationism view, the displacement of concepts is central for the formation of novel concepts.

Schön (1963) identified four phases state the displacement of an old concept into a new situation: 'transposition', 'interpretation', 'correction', and 'spelling out', where a new metaphor, hypothesis or concept is elaborated. The old concept is corrected to suit the new situation, as would be suggested by the model of the old concept as a kind of stencil fitted over the new situation. The displacement of concepts is apt to occur in a difficult, puzzling, new, confused or obstructed situation, Schön argued. This point agrees with what Dewey (1938) called the 'problematic situation' where there is nothing problematic for the subject to start with, a kind of 'what would happen if …' situation. This is linked also to the notion of *fixation* effect when a sudden mental insight is needed to overcome it.

Design *fixation* is a phenomenon that was first studied in design cognition research by Jansson and Smith (1991). They hypothesised that designers who were shown pictorial examples before idea generation would experience a mental block, reducing access to other ways of solving the problem. They defined this lack of flexibility in the design process as design fixation, or a 'blind and sometimes counter-productive adherence to a limited set of ideas in the design process'. *Attachment of concepts* could be seen either as a strategy to solve the problem or as narrowing the design process to an early dead end. A fixation effect might spread if the attachment to a certain concept constrains the transformation of idea from one state to another.

Incubation is another important aspect to address in order to understand the context beyond the emergence of creative insights. Finke et al. (1992) stated that incubation occurs whenever fixation dissipates and proposed that it refers to the case when the design problem is set aside temporarily after an initial impasse is reached. Reporting on the failure to solve a problem through initial attempts, Perkins (1981) debated that incubation helps to achieve the sudden realisation of ideas at unconscious level. Some views hypothesise that the more the designer remains attached to a certain concept from the early stage in the design process towards the end, the higher the probability of a fixation effect occurring. As the designer reaches mid and final stages, the more the process becomes highly structured, the perseverance on one concept gets stronger, and the probability for novel alternative ideas to emerge reduces. However, these assumptions cannot be postulated as absolute in every situation in the design process. If a new dimension is introduced to the problem space, the design process is subject to a shift from the prevalent concept to another one. In some cases, paradigm shifts are considered drastic and pivotal to moving the whole design discourse along.

It is necessary to address the causes for the paradigm shift to understand the nature of design process and formation of novel concepts. It is hypothesised that the sudden mental insight has a strong relation to design novelty. In this research, we investigate whether the occurrence of incidental moments act to structure the design process and emergent actions or not. It could be argued that the resulting stimulus response, necessary for the sudden mental insight, does not come from 'nowhere' or 'out of the blue'. Rather it is likely to come from synthesis with the preceding thoughts in the mind. However, it remains to find out the reasons for the stimulus response to occur and the implications after emergence. A proposed scenario to examine the effect of incidental insights in the design thinking process is to investigate whether it 'reframes' the original concept or 'restructures' the design problem – reformulates the design brief. Sternberg (2003) identified two states that the design actions might be undergoing: 'preserving the flow' or 'defying the crowd'. Thus, identifying the type of emergent actions through design process verifies the ways the concepts are transformed from one state to another, from one medium of representation to another.

These aspects have been introduced in several studies. Paton and Dorst (2011) conducted experiments to reveal the relation between 'briefing' and 'reframing' in situated practice. They stated that the ability to reframe a problematic situation in new and interesting ways is widely seen as one of the key characteristics of design thinking. 'Reframing' during 'briefing' has the aim that designer and client negotiate a mutually understood frame that is actionable. One explicit way in which designers shift clients from a 'problem-solving' approach to one that allows for the negotiation of new frames is through *abstraction*. Kees Dorst considered the effective role of 'framing' and 'reframing' the design problem as the key to generating good solutions (2006, 2009). He explained that the creative design process is when good designers ignore the original problem, focus on the large context, create a new problem and see if it answers the original one. In the following section, light is shed on the research methods that we aim to adopt in order to describe the design processes and emergent phenomena.

1.2 Spectrum of Research Methods

The rational way to investigate the phenomena associated with the design process is to set a hypothesis that pertains to the effect of a certain variable, create controlled experiments and test the effect in the absence and presence modes of the variable. However, this is conditional on controlling every confounding variable that is involved in the design process. After observing a variety of architects participating in a series of pilot studies, it is clear that it is difficult to control some variables, such as: the role of designing tool or software, the type of project and familiarity of its functional programme, the set of specifications and condition provided with the design brief, the mode of designing (collaborative or solo), the expertise and knowledge of the architect, the flexibility of using the design tool, and the accumulative experience of the project's type, and so forth.[7]

Since the nature of design is highly complex and multivariate and differs from one case to another, the experiments should not be forced into testing certain hypothesis or variables. Rather, empirical data will be collected by examining a variety of design projects and briefs. Two experiments are conducted, one providing licence to the participating designers to design freely (with no intrusion from the researcher/observer) and the other including certain specified functional requirements and conditions for design. The functional programme will be diversified to widen the study sample in order to assure the reliability of conclusions and the empirically gained evidence. Thus, the inductive approach is adopted to conduct this empirical study. Data from the case studies will be recorded in addition to our ethnographic observations and accompanied by the architects' retrospective comments on the designs and concept development. Every designer is requested to retrospectively comment and explain how the concept is developed from one sketch to another and from one interim artefact to another. By recording the activities associated with each design case study and demarcating the events on the linkograph, the common phenomena among the cases and the differences that distinguished each case can all be identified.

The two design experiments are outlined and different design briefs are presented to the participating architects. One task presents the functional requirements and specifications to design a 'cheese factory', while the second task permits the designer to design an 'expo pavilion' freely without any intervening conditions. The familiarity with designing each project task differs from one architect to another and is another aspect to be taken into consideration in examining the design process. The recorded design protocol of each architect is analysed in light of the collected ethnographic observations and the designer's retrospective comments. Thus, this research adopts an inductive methodology to conduct the empirical study and investigate the emergent phenomena in design process and creative discovery.

Protocol methods are deployed to capture the structure events in the design process. It is suggested in this research field to monitor the cognitive activities, design actions and structure of events that take place in the design process. The design process is non-linear, non-recursive and non-discursive. As scientists strive to understand the ways the designers think, a variety of methods are proposed to describe the critical events that affect the decision-making process. Protocol methods help to unfold the structure of reasoning and creativity in the design process (Goldschmidt, 2014). Protocols have received special attention from researchers in this field to understand how the activities evolve and the formation of concepts. Protocol methods are divided into two main groups: first, the 'process-oriented' protocols, which describe the general taxonomy of problem-solving, i.e. 'strategies', 'goals', 'problem formulation'; and second, the 'content-oriented' protocols, which describe the contents in the process, i.e. 'what designers see', 'attend to', 'think of', or 'retrieve from' (Dorst and Dijkhuis, 1995).

1.2.1 Challenges of Research

The first challenge is how to segment the design process into its basic units in a way that captures the structure of reasoning. In the first attempt, a joint model of protocol analysis will be developed to process the 'segmentation' (Suwa et al., 1998a) and 'representation' (Goldschmidt, 1990). The dependency relations (codes) between the resulting segments are detected and the linkography is constructed. The level of segmentation of the design actions (units) is tested and evaluated in the linkograph using different quantitative measurements. The objective is to avoid capturing trivial actions that could degrade the value to the network and weaken the resulting analysis. This initial model will be evaluated in light of the results of pilot case studies. Building on this assessment, the model will be subject to cycles of revision and reformation until it is possible to determine precisely how the design of units can be segmented to capture the structure of reasoning precisely. In addition, the aim is to define procedural steps that can be followed by any researcher in this field to analyse other design processes in other contexts.

The second challenge is to test the 'reliability' and 'objectivity' of the model between the quantitative and qualitative analyses, which are proposed to describe the design events on the micro-level

[7] More insights on the pilot studies are given in Chapter 3.

of the situation by interpreting the reflective practice with the interim products. The design process is segmented into units of 'sketching episodes', which comprise some designing actions. Each resulting sketch is an interim artefact that can be sectioned into episodes, designing actions (moves) and cognitive actions. We ask: is it possible to detect the emergence of creative insights (critical actions) based on a quantitative measure only?

The third challenge is to detect the critical actions, sudden mental insights, and the 'eureka' and 'aha' moments in the case studies. This challenge aims to identify the 'creative quality' for each design action. In doing so, two main parameters are set to examine the design actions: 'reframing the solution' versus 'restructuring the problem'. Hence, the creative quality for each action is categorised based on the spectrum of qualities between both parameters. Sternberg's (2003) model of creative contribution, where actions can be either 'preserving the flow' or 'defying the crowd', is an influence in this categorisation and thus the creative quality for the action is categorised under one of these parameters. The identification of critical actions has received special attention in the field. Critical moves are key frames in the thinking process that are associated with the novelty of design. They are relevant to this investigation in comprehending the formation of creative concepts in the design process.

1.2.2 Research Process

Hillier (1996) stated that the design process is the transformation of thoughts between different incommensurable domains. An important question has arisen during this study, which is pertinent to the appropriateness of adopting the 'inductive' approach versus 'logical-deductive' research methodology, posing the question: *how design research is best investigated*?

The inductive approach of grounded theory provides an explanation of phenomena that is generated from data, according to Hillier.[8] Due to the difficulty in controlling the experiment's complex nature and the multiple variables involved, this research adopts the inductive approach to achieve the following objectives:

- **First**, to examine the setting of design experiment: individual, present collaboration, and disperse collaboration. And to examine various means of design tools: *conventional*, *parametric*, and *generative*.
- **Second**, to develop the segmentation and coding protocols to detect the design episodes relevant to the structure of reasoning, and derive principles for a joint model for qualitative and quantitative analyses.
- **Third**, to gather data as diverse as possible to verify the descriptive model and assure its validation: *internal validation* of this model is associated with to the variety of design problems, while external validation is related to the diversity of architects and expertise. Testing different settings of design tools is considered under the rubric of external validation.

1.3 Structure of Contents

The structure of this dissertation is organised for the purpose of achieving the objectives introduced and the research question.

Chapter 2 begins by introducing the research paradigms that are aimed to understand the nature of design processes and the models that stem from each paradigm.

Chapter 3 looks at the methodology and pilot studies – the empirical research process.

[8] This was stated by Hillier in an interview with the author in 2009. He raised an intrinsic point: the importance of distinguishing between the nature of grounded theory (inductive approach) as a 'research methodology' and design as a process. Hillier was asked: 'If design is considered a 'top-down' not a 'bottom-up' process, would it make any difference to adopt the inductive research methodology rather than the hypothesis testing model of logico-deductive methodology?' Hillier explained the difference between the decision to use the research methodology and the way the architects make their designs, answering: 'The grounded theory is an explanation of phenomena that is generated upon data, while in the design process there is an extra step: a transformation into a different domain that requires to be investigated.'

Chapter 4 starts by introducing the predefined models and examines them in light of the pilot studies. They reveal that the segmentation and coding have to be adjusted to avoid too detailed (trivial) segments that may flatten the structure of linkograph. The pilot studies test the following variables: the role of design tools and media on the emergence of insights and formation of creative concepts in an online collaborative design process. A joint model of protocol analysis is developed to describe the events and segment the actions. The coding model is evaluated through the series of pilot experiments using a freehand sketching solo design process.

In Chapter 5, the quantitative model is introduced to acquire information from the linkograph; the combination between information and syntactical (depth) measures is addressed within the context of linkography and space syntax.

In Chapter 6, empirical studies of the unstructured design brief of the 'expo pavilion' are introduced and described by applying the developed model in order to look at the design process, creative discovery and the emergent phenomena. The formation of concepts, identification of sudden mental insights, eureka moments, the segmentation of design processes and the relation between the content and structure of reasoning are all discussed in this chapter and supported by Appendices 6.1, 6.2 and 6.3. The validity of this model is examined through three different experiments.

In Chapter 7, empirical studies of the structured brief with specifications to design the 'cheese factory' are introduced and described by applying the developed model in order to look at the design process and the phenomena of creative discovery. The formation of concepts, identification of sudden mental insights, eureka moments, the segmentation of design processes and the relation between the content and structure of reasoning are all discussed in this chapter and supported by Appendices 7.1, 7.2, and 7.3. The validity of this model is examined through three different experiments.

In Chapter 8, a novel method is proposed to capture the structure of linkographs and detect the emergence of insight and its role on the structure of reasoning, featured as 'directed linkography' to capture the effect of creative insights between the synchronous and diachronic emergence.

Chapter 9 discusses the findings based on the empirical and pilot studies. This chapter sheds light on the common features that pertain to the models of synthesis, which are implemented in the design experiments, and the configurations of linkography.

In Chapter 10, the conclusions and future research directions are presented.

Figure 1.10 and Table 1.1 illustrate the interim objectives per each chapter.

Chapter 1:	Problem definition, research question and objectives	
Chapter 2:	Research Paradigms that aim to understand the nature of design processes	
Chapter 3:	Research Methodology: - Inductive approach to collecting data - Ethnography to observe architects designing and to record the actions occurring in the design processes - Protocol methods to represent the structure of reasoning and detect the emergence of sudden mental insights	
Chapter 4:	The role of design tools, media, and settings of collaboration on the emergence of insights and formation of creative concepts in online collaborative design process A descriptive model is developed to analyse the design process consists of quantitative and qualitative analyses	Evaluation of the segmentation and coding model in additional pilot studies
Chapter 5:	Development of quantitative measures to acquire information from linkographs: - Information measures - Syntactical (depth) measures - Network analysis	Testing the correlation between the variety of measurements in ordered and structured configurations
Chapter 6:	Describing the design process, creative discovery and the emergent phenomena in the unstructured design project: The formation of concepts, identification of sudden mental insights, eureka moments, the segmentation of design processes and the relation between the content and structure of reasoning	Testing the validity of model and the correlation between the quantitative and qualitative analyses
Chapter 7:	Describing the design process, creative discovery and the emergent phenomena in the structured design project: The formation of concepts, identification of sudden mental insights, eureka moments, the segmentation of design processes and the relation between the content and structure of reasoning	Testing the validity of model and the correlation between the quantitative and qualitative analyses
Chapter 8:	A novel method is proposed to capture the structure of linkographs, detect the emergence of insight and its role on the structure of reasoning; featured as 'directed linkography'	Capturing the effect of insights between the synchronous and diachronic emergence
Chapter 9:	Discussion - Models of Synthesis and Creativity: - Diversity and Originality in the case studies - Configurations of Design Process and Linkography	Capturing the effect of insights between the synchronous and diachronic emergence
Chapter 10:	Conclusions and Directions for Future Work	

Figure 1.10 The interim objectives for each chapter

Table 1.1 The interim objectives for each chapter

Chapter #	Interim objective(s)	Methodological Validation
1	Problem Definition, Research Questions and Goals of the Study	
2	Literature Background and the State of Art	
3	Methodology and Research Process – Outlining the Design Experiments	
PART I	***Methodological Development to Describe the Design Process***	
4	Identification of segmentation and coding schemes to capture the structure of reasoning and design episodes aiming at detecting the critical moves and sudden mental insights of eureka and a-ha moments in the design process	
	Pilot study: ▪ Assuring the reliability of segmentation and coding protocols ▪ Investigating the role of online collaboration settings and desktop sharing medium on the formation of concepts between two disperse located designers ▪ Building an integrative framework of analysis – joint model of Macroscopic Cognitive Scheme (Suwa et al., 1998a, 1998b) and Linkography (Goldschmidt, 1990)	Validation of the segmentation and coding protocols
	A proposition of the qualitative model to inspect the structure of reasoning in the design process, by examining the segmentation process of sketching episodes and design moves to capture the structure of reasoning	
5	Investigating order, structure and disorder states of design processes via linkography protocols: • The state of art: testing Goldschmidt model (1990, 1991, 1994, 2014); Kan and Gero model (2005a, 2005b, 2005c, 2007, 2008, 2009a, 2009b, 2009c, 2010) • Adoption of syntactic depth measure; to test integration for each node in the structure of linkograph. • Investigating the correlation between strings and depth measurements. A proposition of the quantitative model to inspect the structure of reasoning in linkographs, utilising the deterministic information theory to compute strings of information – applied methods	Validation of quantitative measurements contrasting information vs. syntactic vs. network analysis measures
PART II	**Empirically gained evidence on the nature of processes and formation of novel concepts in architectural design**	
6	• Investigating the structure of design process, the formation of novel concepts, and the phenomenon of sudden paradigm changes • Application of the integrative analytical model on three design experiments for unstructured brief of 'pavilion' design for Expo Shanghai, 2010	Internal and external validation for the qualitative and qualitative integrative method
7	• Application of the integrative analytical model on three design experiments for highly structured and specified design brief of 'cheese factory' design	
8	• Directed linkography: Comparing synchronous and diachronic effects of sudden emergence of creative insights on the structure of the design process	
9	Discussion of the Research Outcomes	
10	Conclusions and Future Research Directions	

Chapter

2 The Debate on the Nature of Design Process in the Arcade of Research and the State of the Art

This chapter introduces the variety of views and models that have been put forward aiming at understanding the nature of the design processes. It introduces Simonian versus Schönian views and clarifies the controversy of interpretation and differences between both research paradigms. Further, it sheds light on other attempts that were initiated to investigate creativity in the design process and the formation of concepts.

2.1 Paradigms of Design Research

In the decades since the 1960s, great endeavours have been made in the field of design research to try to understand the nature of the design process. This chapter aims to identify the perspectives from which the architecture design process has been looked at since the 1960s, with the goal of establishing the foundation for this research to investigate creativity and the role of sudden insights in the design process.

2.1.1 Technical Rational View

Design as science was a widely considered concept under the dominance of the technical rational methods of the 1960s. It was particularly called for in the twentieth-century modern movement after World War II with the aim to overcome human and environmental problems that, it was believed at the time, could not be solved by politics and economics. Pioneer architects who supported this movement included Le Corbusier, who in the 1920s had described the house as a 'machine for living' (1926), and Buckminster Fuller (1965), who explicitly called for a 'design science revolution' based on science technology and rationalism. This era was particularly illuminated by Christopher Alexander's *Notes On the Synthesis of Forms* (1964) on a rational method of architecture and planning and Herbert Simon's thoughts in *The Sciences of the Artificial* (1969) and by other scientists demanding design based on 'objectivity' and 'rationality'. This was mainly advanced in the area of engineering and industrial design and was considered a significant shift in the focus within the field until the work of Donald Schön first appeared in 1983 and was considered a changing paradigm of design research. Cross has described this alteration as:

> This change is signified over the last two decades shifting the focus from the aim of creating a 'design science' to that of creating a 'design discipline'; that is by understanding the design process through an understanding of 'design cognition (Cross, 2007b: 41).

Simon (1969) called for a methodological approach to support the concept of design as science backed by a body of analytic doctrine to be taught in universities alongside empirical studies. As it focuses on the study of the principles, practices and procedures of design, this paradigm centres on Popper's theory of 'conjecture and refutations' (1963) and Kuhn's 'structure of scientific revolution' (1962), where design is heralded as the 'utilisation of a scientific knowledge of artefacts' as well as an 'explicit scientific activity'; organised, rational and preconceptualised through a wholly schematic methodical approach (Cross, 2007b). However, this technical rational approach faced counterreactions in the 1970s because it deals with well-defined and specified design problems and is not equipped to understand the ill-defined unspecified problems of architectural design, as identified by Rittel and Webber in 1973.

2.1.2 Epistemology of Practice View

Horst Rittel and Melvin Webber (1973) characterised the nature of architectural design and planning problems as 'ill-defined' or 'wicked'. They looked at how designers could solve problems that are defined as wicked because of the complexity in which everything relates to everything else and thus problems may emerge all the way through the process. This was incompatible with the prevailing stream in science and engineering that dealt with 'well-defined', 'tamed' problems. The backlash became explicit when Christopher Jones (1970) abandoned his earlier ideas on 'machine language', 'behaviourism', and the continual attempt to fix the whole of life into a 'logical framework'.

Rittel and Webber argued that if a problem could be well-specified, then actually it was not a problem any more. They stated that wicked problems are the ones where the problem is very hard to specify, and because there are many things that architects do pertaining to design, that component of wickedness exists in architectural work.

Revisions within the wave of *rationalism* influenced the debates on design methodology, primarily those centred on Alexander's method of design – the proposition for an Indian village in *Notes on the Synthesis of Forms* (Alexander, 1964). A proposition of a *rational methodical* approach to architecture design and planning was widely disputed in the field of design research despite the clear distinction that Alexander made then between *design* and *science*: 'Scientists try to identify the components of existing structures, designers try to shape the components of new structures' (Alexander, 1964).

In 1984, he withdrew from the methodology of the time clearly stating that:

> I've disassociated myself from the field … There is so little in what is called 'design methods' that has anything useful to say about how to design buildings that I never even read the literature anymore (Alexander, 1984).[9]

Alexander's earlier thoughts were seriously critiqued by Steadman (2008), an extensive criticism that led to a reformation within rationalism. A critical distinction was made at this point towards building an appropriate paradigm for design research in the 1980s. In the Design Research Society Conference in 1980, a consensus was reached on moving on from making comparisons between science and design and instead to look at *how science could probably learn from design* (Cross, 2007a).[10] Cross et al. (1981) advocated this message and claimed that: 'the epistemology of science was in any case in disarray, and therefore had little to offer an epistemology of design'. Glynn (1985) argued that 'it was the epistemology of design that has inherently conceived our logic of creativity and the hypothesis of innovation that has proved so elusive to the philosophers of science.' Despite the claim of the Design Research Society Conference 1980 (Jacques and Powell 1981), the competition between the two streams was still growing when Archer in turn characterised design research as: 'A form of systematic inquiry performed with the goal of generating knowledge of the form/embodiment of design, composition, structure, purpose, value and meaning of human-made things and systems' (Archer 1981, quoted in Bonsiepe, 2007: 27).

Models of design were formed based on both paradigms; the *rational methodology* and *design epistemology*. Epistemology of practice was originally called for in the 1980s as an attempt to claim an appropriate model that accounts for practice and profession while theorising on 'what design is about'. In spite of those earlier attempts to challenge design methodology, Donald Schön (1983) explicitly challenged the *positivism* dogma underlying the principles of rational methodology by building a constructive memorandum based on the *epistemology of practice* that exists in the intuitive processes that dealt with uncertain practices. It is a constructionist view of human perception and thought processes. He put forward the theory of *The Reflective Practitioner* (1983) based on the abilities displayed by competent practitioners who deal with 'uncertain', 'unique' and 'problematic' situations, coming up with a paradigm that is rooted in the profession. In this context, design is defined as a *reflective conversation with the situation* and design problems are actively set or 'framed' by the designers themselves. Design is not just a process or a profession, but rather experienced as a situation where the designer takes action to improve the perceived current situation.

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[9] Alexander went back on his own claim of a methodical design process. This revision was crystallised an interview with Max Jacobson (Alexander, 1984).

[10] 'There may indeed be a critical distinction to be made: method may be vital to the practice of science (where it validates the results) but not to the practice of design (where results do not have to be repeatable, and in most cases must *not* be repeated, or copied). The Design Research Society's 1980 conference "Design:Science:Method" provided an opportunity to air many of these considerations.[15] The general feeling from that conference was perhaps that it was time to move on from making simplistic comparisons and distinctions between science and design; that perhaps there was not so much for design to learn from science after all, and rather that perhaps science had something to learn from design. Cross *et al*. further claimed that the epistemology of science was, in any case, in disarray, and therefore had little to offer an epistemology of design.[16]' (Cross, 2007a: 43) [footnotes: [15]Jacques R, Powell J (eds) (1981) Design: Science: Method. Westbury House, Guildford; [16]Cross N, Naughton J, Walker D (1981) Design Method and Scientific Method. In: Jacques R, Powell J (eds): Design:Science:Method. Westbury House, Guildford].

2.2 Simonian Positivism versus Schönian Constructionism

Simon (1969) and Schön (1983) presented two different paradigms that can be clearly distinguished. Simon's proposition of the 'sciences of the artificial'[11] is seen as a positivist view claiming a 'technical rationale' to build a fundamental common ground for all intellectual endeavours across art and science. He describes design as the process of making the artificial. On the other hand, Schön's 'reflective practice' is seen as a constructionist suggestion that can be thought of as an 'interdisciplinary' study of design, accessible to all parties involved, which covers both creative activities and the processes of making.[12] Simon's problem-solving approach was seen as capable of solving well-formed and well-specified problems but not considered appropriate for dealing with wicked ones, while Schön's ideas were criticised for the difficulty in creating an interdisciplinary approach for design research that requires a range of knowledge from different domains and practices beyond the designer's awareness and hard to comprehend even for a scientist (Dorst and Dijkhuis, 1995). In the words of Nigel Cross (2007b: 46): 'It is the paradoxical task of creating interdisciplinary discipline … this discipline seeks to develop domain-independent approaches to theory and research in design.'

Simon's approach is clearly considered a *search* process based on the information-processing capacity of the researcher, whereas Schön's constructionism deals with the activity of design. It captures the contents and decisions of the design process in the way designers experience it. As a shifting paradigm, the *epistemology of practice* was developed through workshops and symposia, such as *Design Thinking Research Symposia 1991*, and via a series of empirical studies carried out by Cross (2001, 2002), Cross et al. (1996), Lawson (1994), Akin and Akin (1996) and other researchers on outstanding architects and engineers. Dorst and Dijkhuis (1995) explicitly drew the distinction between Simon's positivism of *rational problem solving* and Schön's constructivism of the *reflective practice*. They conducted a comparative study to capture the design activity as experienced by the designers themselves, where each paradigm expressed substantial and complementary strengths for gaining an overview of the whole range of activities in design. Some of the key findings to distinguish the strength of each paradigm in understanding design in light of the Dorst and Dijkhuis (1995) study are outlined below.

1. The *reflective practice* theory takes into consideration the *situation* aspect under practice based on describing *content-based* decisions. It is advocated that observing the situation aspect in the design process addresses the way designers perceive, recognise and experience problems. On the other side, for the *rational problem-solving* approach it is necessary to step outside the design situation and view actions as *process-oriented* decisions, which help to observe the stages of design as a whole. Design decisions are generally classified into two main categories: either *content-based* perceived actions of the current situation, or as *process-driven* decisions when the designer is making an overall plan or checking the whole progress. Types of decision-making constitute the subject that should be addressed to understand design activity. Thus an appropriate approach to understanding design is needed to preserve this link between the *process* and the *contents* as well as to capture the structure of reasoning according to the architect's perception of the design situation based on elementary step-by-step cognitive actions.

2. In Schön's theory, the *unit* of designing is not a design concept but a 'frame of action'. The frames are based on an underlying background, corresponding with the personal view of the designer on design problems and goals. This leads the encoding system to be very much *content-focused*, where the elements of process are the focus of the designer's problem-solving strategy. This is advantageous in representing the formation of design concepts where the consistency in observing design activities is clearer than the rational problem-solving approach. By this, it conserves the bond between the process and contents of the design problem-solving process.

3. The design problem is set and framed by the designer where the core skill lies in determining how a problem should be tackled. It is a kind of recurring response, based on how the structure of the problem is perceived by the designer. The content of the situation is hence perceived and formed according to the design problem. The kind of perception and the response to the design situation differ from one designer to another. This had always been left to the professional knowledge of experienced designers themselves to recognise while designing and had not been considered describable or promoted

[11] The paradigm has different names such as: design as science, epistemology of science into design, technical rationality, design methodology, problem-solving, and information processing.
[12] Creativity can be seen through both perspectives: 'artificial intelligence and computation' versus 'creative cognition'.

as a disciplined approach until Schön introduced the reflective practice theory giving several examples to describe practitioners' activity.

4. The 'reflective conversation with the situation' paradigm operates on an individual basis of actions and may be dismissed for not providing a very structured path or for lacking rigour in comparison to the firmness achieved by the 'rational problem-solving' paradigm that searches for the rigour of objectivity in design. However, another point of view sees Schön's theory setting up this required rigour in a generic way that provides the opportunity to explore the process based on two principal points: the identification of the structure of the design problem, and the basis set up for judging the appropriateness of a certain frame of action. These points challenge the theory of design as a *reflection-in-action*.

5. The design process can be looked at from two perspectives: the *conceptual stage* where the designer proposes initial solutions to a particular problem structure, and the *standard strategy* of the overall process. The reflection-in-action process operates particularly well with the conceptual stage inseparable from the strategy, while the rational problem-solving process is appropriate for describing clear-cut situations for the standard strategy. In seeing design as a reflection-in-action it is still possible to describe the activity without loosing the link between the contents-based decisions and the process components.

6. Making process-driven decisions requires the designer to step out of the design situation. This is a wholly different way of thinking from the content-based situation. Process-driven decisions, which are not part of the core design activity, are the object of many of the rational methodologies. However, the design situation is controlled by the designer's perception of the emerging problem, goals, and the possible action of the next step. Addressing these aspects reflects the core nature of design activity, which exposes the shortage of procedural approaches if the aspect of 'situation' is disregarded in the attempt to describe the problem-solving process. Looking only at the overall components of largely content-based decisions limits the power of the methodology. This in fact favours the attempts that are made to address at least some more aspects of the design situation.

7. The reflective practice inherently preserves the bond between the content-based and process components of the designer's actions and thus is evidence of the designer's intuitive recognition.

Designers are active in structuring the design problem. Dorst and Dijkhuis (1995) argue that they do not evaluate concepts but rather evaluate their own actions in structuring and solving the problem through the process. Thus Schön's theory in essence tackles the structure of the design problem where designers work by framing a problem, making moves towards a solution and evaluating these moves on the criteria of the coherence of reasoning, accordance with the specifications, and the problem-solving value (Dorst and Dijkhuis, 1995). In contrast, rational problem-solving does not provide this basis for the structure of design problems but is, however, helpful in comparing components of different design processes.

2.3 Through the Eyes of a 'Designer-Researcher'

Nigel Cross points at the progress that was made by 'designers-researchers' in developing the methodology of research. He states 'design grows as a discipline with its own research base' (Cross, 2007b: 49). This is conditional on the researcher's acquaintance with the domain and having a prerequisite intellectual capacity in various bodies of knowledge to form a determinant domain-independent discipline. The paradigm of design epistemology could then be threatened with attempts to import methods from other non-design disciplines that deny the specificity of design or anything special about its activity, implying that it is just another or typical form of problem-solving or information-processing.

Our aim to derive the taxonomy of design paradigms is to comprehend the context beyond the proposition of models with the purpose of understanding the design process. The shown taxonomy is observed to have a dominant influence shaping the models that were proposed to look at design. They are basically clustered around Simon's technical rationality or centred on Schön's reflective practice. Hence, we arrive at the difference of studying the design process through the eyes of the 'rational problem solver' or the 'reflective practitioner' where:

The *rational problem-solver* is an information processor who seeks rigour based on objective reality, adopting a rational search process and optimising scientific laws and knowledge of design procedures.

The *reflective practitioner* defines his/her own problem and design situation, and frame of action, and constructs his/her own reality based on a reflective conversation with the situation and artistry of design by choosing the time and context to apply the procedure of knowledge. Design is not just a process or a profession, it is experienced as a situation that a designer finds him/herself in.

2.4 Mapping the Terrain of the Design Models

The aim of building a chronological study of design paradigms is to map the terrain of design models. The 1960s' philosophy of Karl Popper had an influence on the methodology of rational paradigm for a long time. Popper's view can be abstracted in the following points:

First, he draws a distinction between logic and empirical sciences giving a restrictive view of logical forms, scientific hypothesis and probability theory. The theory stands opposite to all attempts to operate with the ideas of inductive logic. Along familiar lines, Popper sees typical scientific hypotheses as universal and they must be drawn from objective derivations. The hypothesis is characterised by its capacity to be proved false; it can be falsified by one contrary instance, not by any inductive support or any degree of probability, and that is what makes it scientific. Thus this approach rejects any subjective theory of probability.

Second, Popper states that an inductive approach cannot formulate a complex theoretical model from a series of inductive generalisations and that one could not logically induct complex models of the inner working of nature as it must be first imaginatively conjectured, then refuted or supported by rigorous testing against data (Popper, 1963, cited in Hillier, 1996: 323). Hillier et al. (1972) supported Popper's view and proposed the *conjecture-configuration-analysis* model to interpret the design thinking process. While a commonly held theory of designing stated that designers should resist bringing their own preconceptions to bear on a problem, Hillier et al. proposed the *conjecture-analysis* theory that a designer would pre-structure a problem in order to solve it; that is, existing knowledge and previous experiences would be used to influence the nature of the solution.

However, March (1984) considered the chief mode of reasoning in design is inductive and developed a model of *production-deduction-induction* (PDI), which basically states the need to integrate abductive reasoning with conventional (classical) forms of reasoning such as deduction and induction in order to describe the evaluative and analytical aspects of design as well as creative activities in the process.

This is a triple-activity model that is based on Pierce's (1923) clarification of abductive reasoning. In the first phase of *productive* reasoning, the designer uses preconceived knowledge to initiate a solution, while in the second phase of *deductive* reasoning, the deduction of a solution is derived from analysis of the process. In the third phase of *inductive* reasoning, some aspects of the design are modified, altered and improved in order to produce a better solution. This process is considered to have a very cyclic nature like other solution-oriented (technical-rational) models.

Gui Bonsiepe (2007) described the relation between *design* and *design research* as 'uneasy', which could be attributed to the unsubstantiated basis of *design science* when it has no influence on *design practice*.

> The conceptual model in Kirchmann's comment[13] may, when transferred to design, mean that although design science is a genuine science, it has no influence on design practice; or that design science is not a science because (as the philosophers put it) it does not fulfil the requirements of a true concept of the latter. It is the task of science to 'understand its subject, discover its laws, with the aim of creating concepts, of identifying

[13] The Kirchmann model is an attempt to mediate between *realism* and *idealism*. This was reflected in his philosophical writings: *The Worthlessness of Jurisprudence as a Body of Knowledge*, 1848; *A Realistic Foundation for Aesthetics*, 1868, both cited in Bonsiepe 2007.

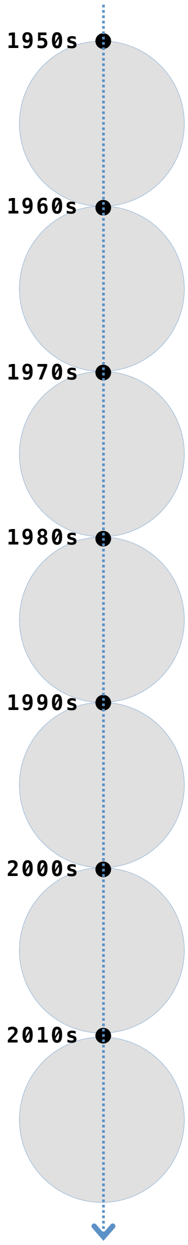
> the relationship and connections between the various phenomena and, finally, of assembling its knowledge in a simple system (Bonsiepe, 2007: 26).[14]

Distinguishing the paradigms of research from being oriented to *science* or *discipline* has been reflected in researchers' attempts to define and classify the proposed models for the design process. It is crucial to bridge the *characteristics* of design models and *epistemology* of design practice while tending to analyse a design process to ensure a reliable method. Leading these attempts are: the 'designerly ways of knowing' (Cross, 1982; 2001, 2007a); the 'prescriptive' models (i.e. 'generate-test') (Simon, 1969); 'conjecture-configuration-test-refutation' (Hillier, Musgrove and O'Sullivan, 1972, 1984); 'analysis-synthesis-evaluation' (Jones, 1963,); 'industrial design process' (Archer, 1969); 'analytical-creative-executive' (Archer, 1984); 'analysis-synthesis-evaluation' (Markus, 1969; Maver, 1970); 'exploration, generation, evaluation, and communication' (Cross, 1994); 'analysis-concept-embodiment-detailing' (French, 1999); 'clarification of the task, conceptual, embodiment, and detailed design' (Pahl and Beitz, 1996); VDI 2221 stage-based model (VDI, 1993); 'function-behaviour-structure' (Hybs and Gero, 1992); 'co-evolutionary design process' (Maher and Tang, 2003) and the 'descriptive' models (i.e. 'perceived situated errors and corrections') (Argyris and Schön, 1978); 'reflective practice' (Schön, 1983); 'situated transformation of information into knowledge' (Kolb, 1984); and 'structured reflective practice' (Gibbs, 1988; Brookfield, 1998; Johns, 1995; Rolfe et al., 2001).

Awareness of all the varieties of bodies of knowledge about design has grown, particularly the initiative of the Royal College of Art (RCA) (1979), where Bruce Archer and colleagues called for a third culture (as opposed to the dominant two 'cultures' of education in science and education in the arts and humanities) to serve design education, which was addressed as: the 'collected experience of the material culture, and the collected body of experience, skill, and understanding embodied in the arts of planning, inventing, making and doing'. Those important attempts are specified below. Illustrations of key models in design studies are shown in Figures 2.1 and 2.2.

[14] Bonsiepe (2007: 26) has made the point that the English term 'design', does not distinguish between design and what the Germans call *Entwurf* (project) and 'there are reasons why the term "design" should be used carefully in both languages. Everyone is entitled to call him- or herself a designer, especially as people generally equate design with the things they see in lifestyle magazines. Not everyone would suddenly call him/herself a project-maker … because this carries an overtone of professionalism that the word design has lost. As an alternative, we could use the German expression Gestaltung. The only problem is, of course, that it has no equivalent in other languages. For although it refers to design, it does so primarily from the perspective of perception (Gestalt psychology) and aesthetics.'

- **1926:** ***Wallas***, The creative problem-solving model
- **1933:** ***Dewey***, Reflection as a specialised form of thinking
- **1948:** ***Shannon and Weaver***, The Mathematical Theory of Communication



- **1959:** ***Evans***, Solution-Synthesis concentric model –Spiral model of combined stage
  Popper, The Logic of Scientific Discovery
- **1962:** ***Kuhn***, The Structure of Scientific Revolutions
  Hall, Asimow, the iterative nature of design process – Stage-based structured process
- **1963:** ***Popper***, Conjectures and Refutations
  Johns, Analysis-Synthesis-Evaluation
- **1964:** ***Alexander***, Notes on the Synthesis of Forms
- **1966:** ***Levi Strauss***, *The Savage Mind*
- **1969:** ***Simon***, The Sciences of the Artificial

- **1970: Eastman**, First protocol analysis
- **1971:** ***Piaget***, *Structuralism*
  - **1973:** ***Rittel and Webber***, Ill-structured design problems
- **1974:** ***Hillier, Musgrove, and O'Sullivan***
  - **1978:** ***Schön and Argyle***
- **1979:** ***Steadman***, The Evolution of design
  Darke, The Prime generator – Conjecture-analysis model
  Bateson; Johnson-Laird 1988, Creativity is about Randomness and Chance

  1981: ***Weisberg and Alba***, Incremental Creativity
  Perkins; ***Ward* et al.**; ***Weisberg* 1986**; Creative Discovery as systematic and structured process
- **1982:** ***Cross***, Designerly Ways of Knowing
  Hubka; French 1992, Feedback loops between stages
- **1983:** ***Schön; Akin* 1986**, Reflective Practice
- **1984:** ***March***, Induction-Production-Deduction
  Daley, Empiricism
- **1987:** ***Rowe***, Synthesis-Decision
  Metcalfe and Weiße, Sudden insight, unconscious, rapid cognitive restructuring

- **1990:** ***Goldschmidt***, Linkography
- **1992:** ***Finke* et al.**, Geneplore Model
- **1994:** ***Cross***, Four-based model
  Blessing, Linear Stage-based process – Concentric iterative form
  Boden, Dimensions of Creativity
- **1998:** ***Suwa* et al.**, Macroscopic Cognitive Scheme

- **1999; 2003:** ***Sternberg***, Creative Qualities for creative contribution

Figure 2.1 A chronological development of the key models in the field of *design research*

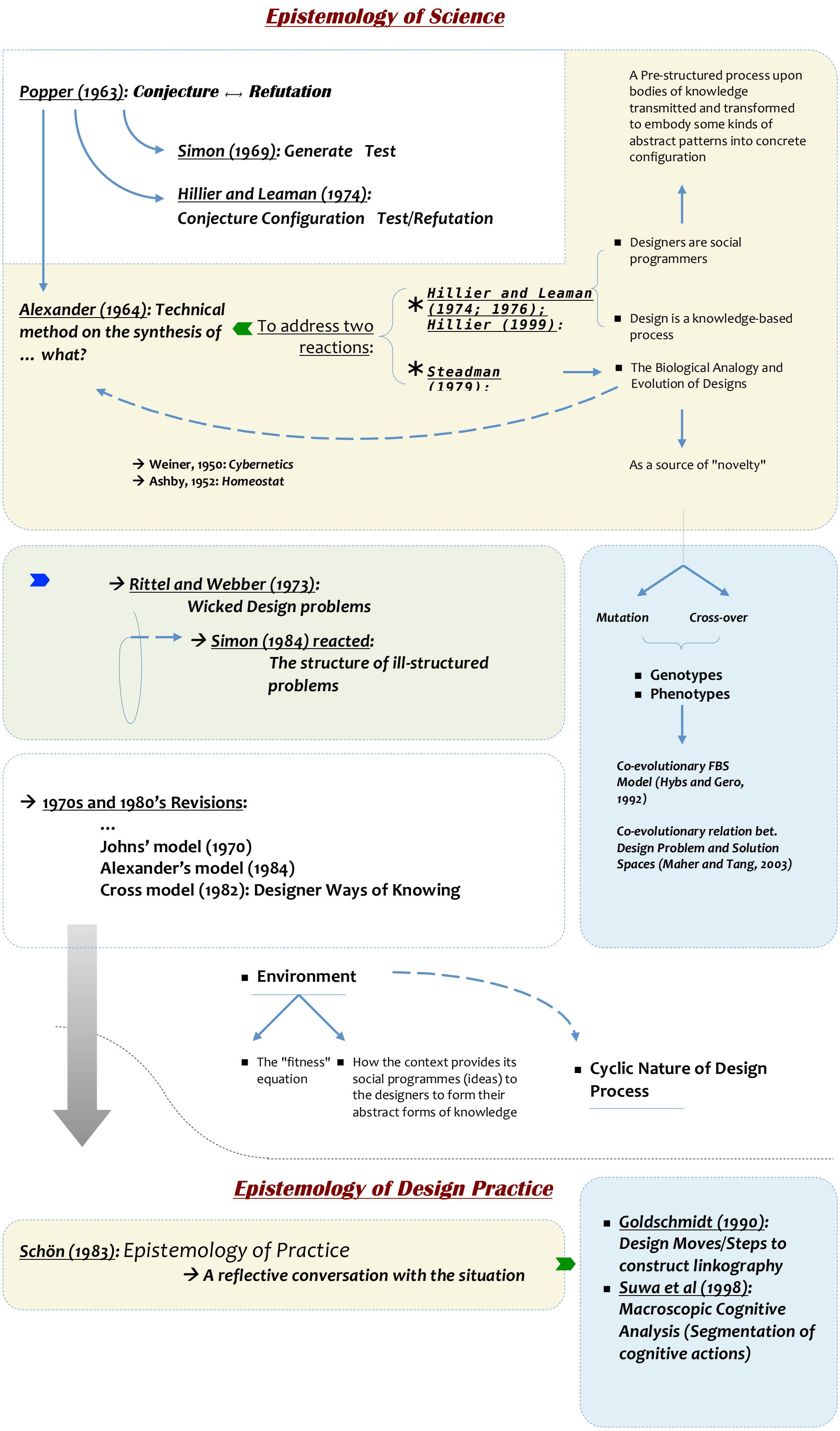


Figure 2.2 A chronological development of design paradigms; categorising and grouping the terrain of design models

2.4.1 Designerly Ways of Knowing

In order to understand what *design* is actually about, Cross (2006) conducted a study to contrast *science* and *humanities* with *design*. Three axes were identified in this elaboration; the *phenomenon of study*, *appropriate methods*, and *values*; see Table 2.1. Based on this identification, Cross explained some of the key points to understand the 'nature' of design processes and design products. The proposition of 'designerly ways of knowing' covers several points that pertain to design *processes* and *products*.

Cross (1982, 2001, 2007a) claimed in his view about the *designerly ways of knowing* that it is a culture that pertained to the 'ways of thinking and acting', to form a consensual approach towards building an *appropriate paradigm* for design research. The designerly ways of knowing fulfils concerns of design research to be the development, articulation and communication of design knowledge. This view proposed to build formal bodies of knowledge of *shape* and *configuration* as well as theoretical studies of *design morphology*. These bodies should be concerned with the *semantics* as well as the *syntax* of form; the relationships between *form* and *context*. Our concern to describe the relation between the *content* and the *structure of reasoning* aims to build a body of knowledge about the design process. In doing so, we look at the attempt by Cross (1982, 2001, 2007a) who identified five aspects of designerly ways of knowing: architects (designers) tackle 'ill-defined' problems; their mode of problem-solving is 'solution-focused';[15] their mode of thinking is 'constructive';[16] they use 'codes' to translate abstract requirements into concrete objects; and they use these codes to read and write in 'object languages' – non-verbal language of forms of knowledge.[17] Moreover, he identified the nature of *Design* (with a capital 'D') through four aspects, which are:

1. The central concern of Design is the conception and realisation of things.

2. Design encompasses the appreciation of material culture and the application of the arts of planning, inventing, making and doing.

3. Design is based on the language of *modelling* that can be developed similar to the language of *numeracy* in science, and the language of *literacy* in humanities.

4. Design has its own *things to know, ways of knowing them, and ways of finding out about them*.

Table 2.1 Identification of three axes to understand the nature of design

	In *Science*	**In *Humanities***	**In *Design***
The phenomenon of study	The natural world	Human experience	The artificial world
The appropriate methods	Controlled experiment, classification, and analysis	Analogy, metaphor, and evaluation	Modelling, pattern-information, and synthesis
The values	Objectivity, rationality, neutrality, and a concern of truth	Subjectivity, imagination, commitment, and a concern of justice	Practicality, ingenuity, empathy, and a concern of appropriateness

Source: Author's interpretation of theories of Cross (2006).

– Design Processes

Cross has distinguished between the design *processes* and *products* through the following characteristics:

1. Based on a study (1994) by Bryan Lawson, who conducted experiments on some outstanding designers, the following conclusions are drawn:

[15] Lawson (1994), Cross and Clayburn Cross (1996) and Cross (2001, 2002) conducted several design experiments and observed a variety of outstanding architects and engineers while designing and came up with the conclusion that architects focus on the solution in most of their attempt to solve the ill-defined problem whereas engineers focus on the problem that is well pre-defined in their design processes.

[16] Looking through the Schönian view of the reflective practice (Schön 1983).

[17] Agreeing with Hillier and Leaman's model (1974), architects use codes to read and write in 'object languages' where *objects* are 'forms of knowledge' (Cross, 1982) of 'non-verbal' *language* (French, 1979).

- *Scientists adopt a 'problem-focused' strategy* while *designers, such as architects, adopt a 'solution-focused' strategy*. Architects learn to adopt their solution-focused strategy during an accumulative experience and education.
- *Scientists solve problems by 'analysis'* while *designers solve problem by 'synthesis'*: 'Science is analytic; design is constructive' (Gregory, 1966); 'Logic has interests in abstract forms. Science investigates extant forms. Design initiates novel forms' (March, 1976).

2. Cross (1982) concludes that a central feature of *design activity* is its reliance on *generating (fairly quickly) a satisfactory solution*, rather than on any prolonged analysis of the problem:

> In Simon's [Simon 1969] inelegant term it is a process of 'satisficing' rather than optimising; producing any one of what might well be a large range of satisfactory solutions rather than attempting to generate the one hypothetically-optimum solution (Cross, 1982).

- The designer is constrained to produce a practicable result within a time frame, whereas the scientist is often required to suspend his/her judgements and decisions until more is known: 'Further research is needed is always a justifiable conclusion for them' (Cross, 1982).

3. *Design problems are ill-defined, ill-structured, and wicked* (Rittel and Webber, 1973). They are not subject to extensive analysis; a clear solution-focused strategy can never be a guarantee to go on analysing the problem (Cross, 1982). A design problem can be contained with manageable bounds of *conjectured solution* (Hillier and Leaman, 1974) and the designer needs to impose a *primary generator* to define the limits of the problem and suggest a possible solution (Darke, 1979).

- *Ill-defined problems are emergent and transformative* and have to be redefined along the process in the light of the solution: 'Changing the problem in order to find a solution is the most challenging and difficult part of designing' (Jones, 1970); 'designing is a process of pattern synthesis, rather than pattern recognition' (Cross, 1982).
- *Design is structured with the bodies of knowledge*, as Levin (1966) stated:

> 'It is a pre-occupation with geometrical patterns to structure knowledge and that a pattern or some other ordering principles need to be added to the information in hand to arrive at a unique solution' (Levin, 1966).

4. This '*pattern pre-occupation*' can be also understood in the process of conjecturing a solution; *pattern constructing, conjectured solution and refutation process* (Popper, 1963; Hillier and Leaman, 1974; Hillier, Musgrove and O'Sullivan, 1984) as a '*preconceived form*' to generate a solution. This rational view states that the pattern pre-occupation that is aimed to conjecture a solution legitimises the viewpoint that the design process is *structured* and that the solution does not arise arbitrarily. This in fact raised an important debate on *design novelty* and *unique solutions*, where the question might be: *do architects have to start from a conceptual basis to initiate a creative design concept*?

> In all fields of design, one finds this preoccupation with geometrical patterns; a pattern (or some ordering principle) seemingly has to be imposed in order to make a solution possible (Cross, 1982).

5. In his extensive studies on constructive diagrams and pattern language, Alexander (1979) defended the argument for '*pattern-constructing*' claiming that this feature has been recognised as '*lying at the core of design activity*'. In Hillier and Leaman's model (1976), they pointed out that designers use codes to convey '*abstract patterns*' of requirements into '*concrete patterns*' of an actual object; forwarding a view of *linguistics* that a kind of '*code*' transforms '*thoughts*' into '*words*'. Cross finds that the '*designerly ways of knowing*' are embodied in these 'codes'.

> What designers know about their own problem-solving processes remains largely tacit knowledge. A skilful designer is a person who knows how to comprehend that knowledge pertained to the design problem. It is an apprenticeship of education to be learned and improved through education and accumulative experiences; to become articulate about their design skills Cross (2006).

– **Design Products**

In the rational paradigm, the interim products are seen structuring the design process, acting as '*bodies of knowledge*' and knowledge is *embodied* in the products of designing: 'A great wealth of knowledge embodied in the objects of our material culture' (Cross, 1982).

Some views advocate the necessity to refer back to existing or preconceived examples in order to know how an object should be designed. Alexander (1964) debated that products of the unselfconscious process of craft design are better outcomes on balance than those resulting from *self-conscious* processes, leading to 'extremely subtle, beautiful and appropriate objects. … A very simple process can actually generate very complex products'; 'The unselfconscious processes tend to generate the material culture of craft society' (Cross, 1982).

Simon (1969) argued that *objects* are *forms of knowledge* that can be used to generate a 'satisficing' solution –to satisfy certain requirements. This rational view raises the question: *Do forms act as aids to creative leaps*? 'Invention comes before theory' (Pye, 1978).

There are two intrinsic characteristics for design products, which are: the '*metaphoric appreciation*' and '*verbal and non-verbal codes*', both of which can be considered key sources for a structured design process.

Products can be seen as outcomes of '*processes of matching, classifying and comparing*'. This is called the 'metaphoric appreciation' by Douglas and Isherwood (1979). Metaphoric appreciation is a work of approximate measurement, scaling and comparison between 'like' and 'unlike' elements in a pattern. This is mainly about particular skill such as that 'used to translate back from concrete objects to abstract requirements through design codes' (Cross, 2007a).

Design processes and *products* rest on the manipulation of *non-verbal codes* in the *material culture*. Codes translate messages in both directions between concrete objects and abstract requirements with the purpose of facilitating constructive, solution-focused thinking. Codes are therefore a 'means of tackling characteristically ill-defined design problems' (Hillier and Leaman, 1974).

2.4.2 Route Maps and Models to Look at the Design Process

Other researchers have made attempts to outline models for the design process according to the prevailing research paradigm of the time. In presenting those models, we aim to draw out the main features of each, which can be distinguished through the type of research paradigm; specifically the *technical rationale* and *epistemology of practice*. In this context, there are two perspectives to highlight; either to focus on the main mechanisms that designers perform all through the design process, or to describe the contents of the process as it occurs. To this end, the features of these models are addressed first before posing any definition that might limit the perspective of what design is particularly about.

Route maps and models of design can be classified in different ways. However, the categorisation processes have taken different forms in this area of research. For example, while there is a taxonomy based on the ways of making decisions of design, which looks profoundly at the nature of the process in terms of 'content' and 'macro components', other endeavours group the models by contrasting the 'activities-based' with the 'stages-based' approach, or distinguishing between the 'solution-oriented' and 'problem-oriented' focus, or by clarifying the difference between the 'abstract' approach and the 'procedural' and 'analytical' methods. The distinction between these characteristics made in the sections aims to provide better understanding of the nature of design models, knowing that some models are located entirely within one categorisation only, while others are commonly located in more than one classification. These models are extensively used to analyse the design process, paving the way to categorise the variety of definitions of 'what design is'. This is evident through the following explanation.

– ***Prescriptive and Descriptive Models***

Cross (2008) distinguishes between prescriptive and descriptive models, where the former type 'specifies the sequences of events that occur in the process in a logical order', and the latter 'describe the events and identify the implication of the emergent action'. In the prescriptive models, a logical approach is adopted to capture the cyclical nature of design, starting from the stage of *tackling a problem* and ending with *generating a solution*, by looking at the overall structure of the design process of process-oriented decisions. Both elements are central to this model because they represent the major components in the design process and thus, the prescriptive models are considered 'problem-focused'. This approach usually offers algorithmic, systematic procedure to follow and is often regarded as providing a particular design method.

Descriptive models, on the other hand, describe the activities of content-based decisions. They reflect the 'solution-focused' nature of design thinking. Moreover, they describe a more or less conventional heuristic process of design relying on empirically gained evidences and consider the aspect of *design situation* to be central to the goal of description. The design situation is a multi-step process of designing that is controlled by decisions and is defined by the designer's perception of the present state of design, goals and possibilities for action (Dorst and Dijkhuis, 1995: 264).

Prescriptive models declare that 'analysis' takes place before starting the design process, with thinking in advance to generate solutions to comprehend the circumstances surrounding the design problem and identify all its important components. As a design methodologist, Jones (1963) has searched for a legitimacy to state the systematic nature of the design process and suggested a basic structure that comprises the stages of *analysis*, *synthesis* and *evaluation*, where:

Analysis is responsible for the determination of all the requirements and scrutiny of a set of logically related performance specifications.

Synthesis searches for the possible best design solution by building up complete sets for each individual performance specification.

Evaluation puts, according to Jones, emphasis on how generated alternatives and solutions fulfil the goals of the performance requirements.

These three stages are particularly dependent on how the performance of specifications are logically derived from the design problem and how the generated solutions are synthesised to arrive at the best solution, making a rational judgement, and fostering it until the process ends. In Table 2.2, a comparison is drawn between the chief characteristics of the prescriptive and descriptive models.

Table 2.2 The main characteristics identifying types of design models

	Prescriptive Models	*Descriptive Models*
Characteristics	• Adopt a rational approach to capture the cycles of design • Consider the decisions that are made on the major components of the design process; '*process-oriented*' decisions • Require analysis to precede the generation of solutions • Are 'problem-focused'; show the cyclic nature of process • Usually offer algorithmic, systematic procedure to follow	• Describe the activities and 'content-based' decisions, • Identify the significance of generation of a solution • Reflect the 'solution-focused' nature of design thinking • Describe a conventional, heuristic process relying on empirical evidences • Consider the aspect of '*design situation*' central to the focus of description

- ***Process-Oriented and Content-Based Models***

Decisions in design processes are taken in two ways; either by stepping out the design situation and evaluate stages or by considering the aspect of design situation and take the decision upon the practiced contents. The first type are 'process-oriented' decisions while the second are 'content-based' decisions. In this classification, the models can be classified according to this taxonomy of design decisions, overlapped with the classification of prescriptive and descriptive models.

Process-oriented models consider the overall components of the design process rather than micro activities. Likewise, prescriptive models anticipate process-oriented decisions. Thus both types of models commonly characterise the cyclic, iterative, highly structured, stage-based nature of the design process. These models are dependent on the logical and rational derivation for the stages of design.

Wynn and Clarkson (2005) presented a taxonomy based on contrasting types that distinguish between the process-oriented and content-based models: (a) models of stage-based versus activity-based, (b) solution-oriented versus problem-oriented models, and (c) abstract versus procedural versus analytical approaches.

- ***Stage-Based and Activity-Based Models***

This classification is based on a two-dimensional perspective of a cyclic process, based on Hall (1962), who defended the argument and suggested that for any engineering system, phase-based structure lies orthogonal to the iterative problem-solving process that takes place within every phase. This approach has explicitly legitimised the cyclic and iterative nature of the process.

Asimow (1962) transferred Hall's ideas from the domain of system engineering to that of design, stating that the stage-based structure resembles a linear chronological development of design and describes the stages as the morphological dimension of the design process. The activities are characterised in Asimow's model as highly cyclical, occurring on day-to-day basis and it resembles the problem-solving dimension. Blessing's model (1994) also arrives at the same conclusion and reckons that stages and activities of design take the linear/serial, cyclic, repetitive/iterative and concentric forms. While serial and cyclic models prescribe well-structured, iterative activities within each stage of design (Hubka, 1982), purely stage-based models indicate the possibility of reworking the process using feedback loops between stages (French, 1999). Concentric models, however, identify the convergence state of design and the integration of sub-solutions based on the level of activities in each stage (Evans, 1959), namely 'solution-synthesis'. In Figure 2.3, different types of stage-based and activity-based models are illustrated.

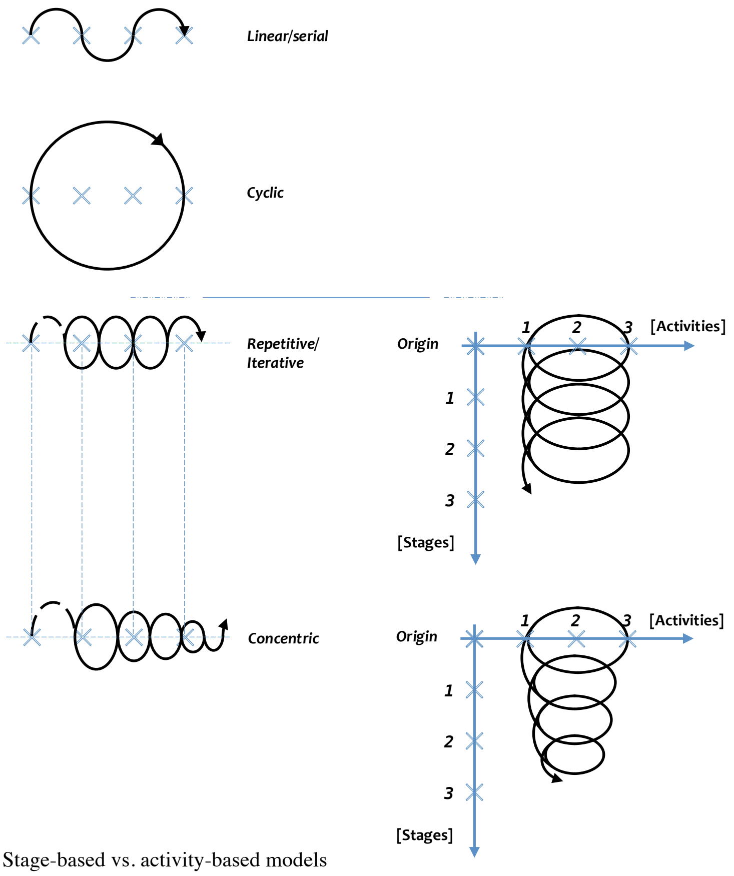


Figure 2.3 Stage-based vs. activity-based models
Source: Blessing, 1994, cited in Wynn and Clarkson, 2005: 36.

- ***Solution-Oriented and Problem-Oriented Models***

Solution-oriented models represent the process that is based on one concept design idea, namely *concept-based* process. Problem-oriented models are based on the abstraction and analysis of the problem structure that lead to generating and making a choice from a pool of generated solutions. They are primarily based on the formulation of a solution-neutral problem statement, and propose that the final design should be more dependent on logical deduction than on prior experience. This assumption, common to all problem-oriented literature, forms the basis of the *procedural* models.

Solution-oriented models, like Hillier et al.'s (1972) model of '*conjecture-configuration-analysis',* include descriptions of the designer's thought process rather than problem-oriented counterparts. Examples of problem-oriented models include Jones (1963), Ehrlenspiel (1995) and Cross (1994); (see Figure 2.5).

Jones's (1963) model of 'analysis-synthesis-evaluation' is a problem-oriented and linear type. The design problem is first analysed then a range of solutions are generated based on synthesis. The set of solutions are tested and evaluated against the set of requirements and objectives to narrow the focus to one solution. Ehrlenspiel (1995) proposed a model for the domain of problem-solving that comprises two operations: *divergence* in the generated solutions and *convergence* during the evaluation and selection of concepts stages.

Cross (1994) proposed the four-stage model of 'exploration, generation, evaluation, communication' with the purpose of exploring ill-defined problems of design. This model is a problem-oriented type; that is, it proceeds by 'exploring the problem, 'generating the solutions, 'evaluating it against the set of goals', and 'communicating to the final product or manufacturing process'. The model assumes that the evaluation stage does not always lead directly to the communication of a final design but has an iterative feedback loop between the evaluation and generation stages in case any error or dissatisfaction occurs in a solution. French (1999) developed a detailed model for the design process that is based on the following activities: 'analysis of problem', 'conceptual design', 'embodiment of schemes' and 'detailing'. The model reflects the hybrid activity and is classified as a stage-based type.

- ***Abstract, Procedural, and Analytical Approaches***

Abstract approaches are descriptive, where the design process is described at a high level of abstraction. *Procedural* approaches, however, focus on a specific aspect of design that is less general than abstract approaches; mostly they are based on a practical situation. *Analytical* approaches describe specific instances of design based on two means: creating a descriptive representation of the process, and developing a technique or a procedure to deploy and improve the quality of understanding of what the design process is about. Abstract models are activity-based in nature and could adopt either a problem-oriented or a solution-oriented strategy, while, in contrast, procedural approaches are stage-based and problem-oriented. Hence we conclude that a taxonomy of models can be commonly presented with three different classifications (see Figure 2.4); prescriptive and stage-based models can take various forms (see Figures 2.5 and 2.6 respectively).

Wynn and Clarkson (2005) distinguished Evans's model (1959) as a different perspective from most of the procedural approaches by proposing a combined stage and activity model concentrating on the iterative nature of the design process. The model is a '*design spiral*', for which Evans stated the interdependency of the variables involved in the design process and therefore it cannot be achieved in a linear way (see Figure 2.7). Wynn and Clarkson said that:

> Most procedural models present design as a series of stages, each of which is visited only once by the ideal process. A different perspective is offered by Evans (1959), who proposes a combined stage and activity model concentrating on the iterative nature of the design process. Noting that one of the most fundamental problems of design lies in making trade-offs between many interdependent factors and variables, Evans' model argues that design cannot be achieved by following a linear process. … According to Evans, such interdependencies are characteristic of design, a view later supported by Eppingeret al. (1994) and many others (Wynn and Clarkson, 2005: 41).

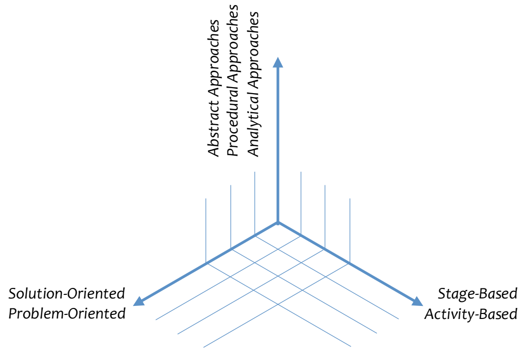


Figure 2.4 Taxonomy of models based on *stages* vs. *activities*; *solution-oriented* vs. *problem-oriented* decisions; *abstract* vs. *procedural* vs. *analytical* approaches

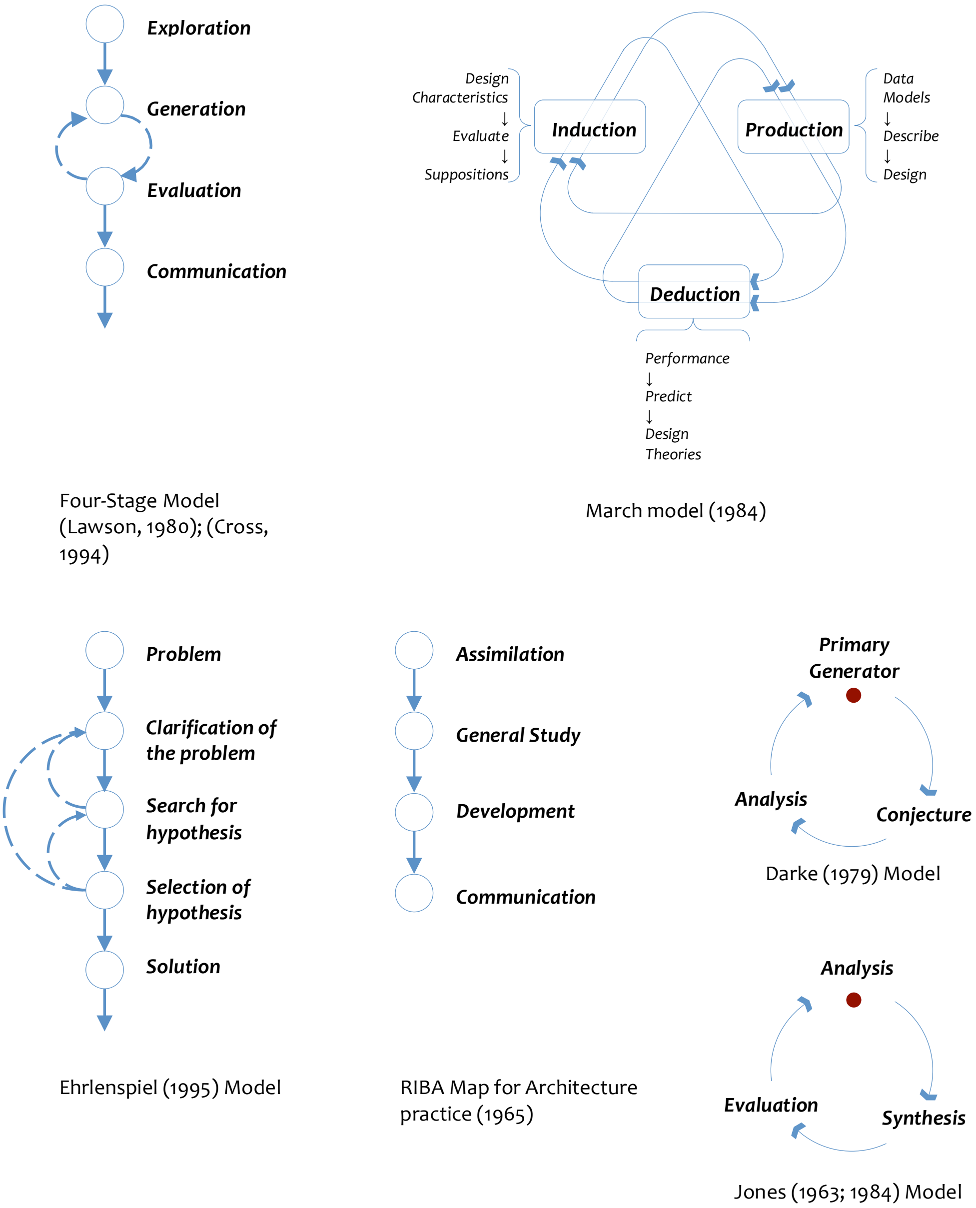
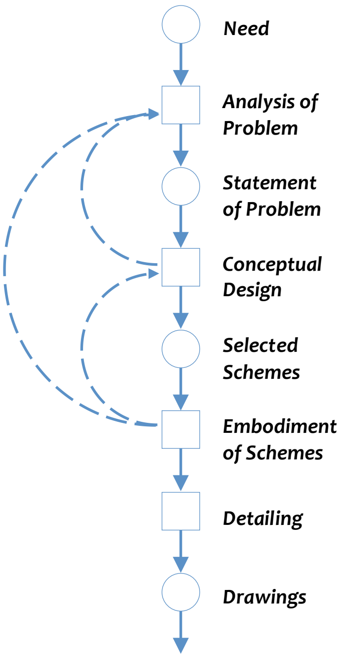
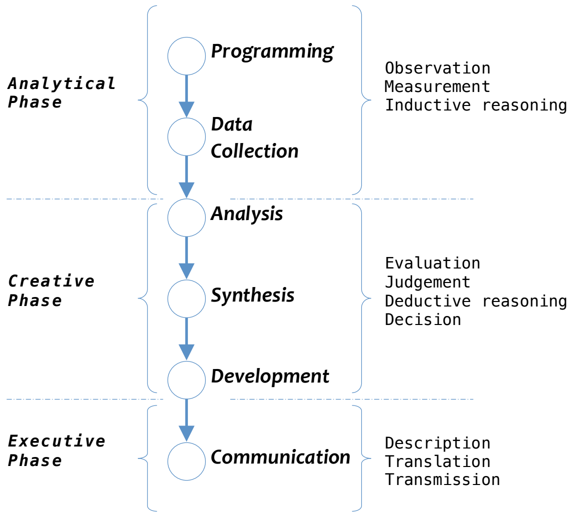


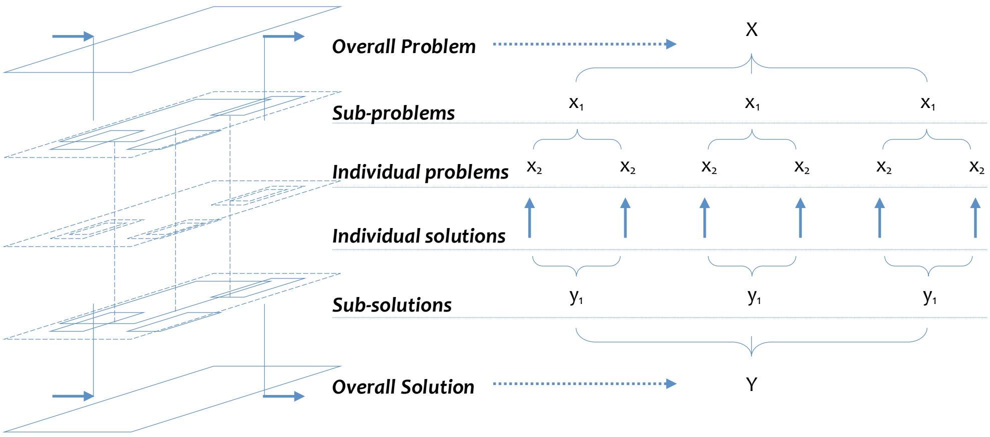
Figure 2.5 Examples of *prescriptive* models



French (1999) Model



Archer (1984) Three-phases Model



VDI 2221 model

Figure 2.6 Examples of stage-based models

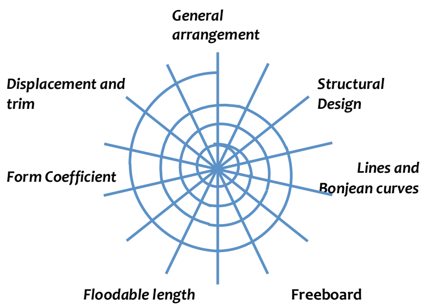


Figure 2.7 Spiral model
Source: Evans 1959, cited in Wynn and Clarkson, 2005: 41.

2.5 Empirical Models

Daley (1984) looked at the theory of *empiricism* and stated that empirical studies are challenged by two views. The first view is a methodologist opinion that criticises the protocol analysis, which gains evidence based on empirical studies because it does not distinguish between the lines of 'analysis' and 'synthesis' as two discrete components of the design process – this opinion is represented by Lawson (2006). The second view advocates that 'analysis' takes part in all the phases of design and that 'synthesis' begins at an early stage of the design process. In support of this argument, Akin (1986) conducted a series of design experiments with experienced architects and found that the 'generation of new goals' and the 'redefinition of constraints' are often recurring from that early stage of the design process.

Describing design according to empirical studies is basically centred on creating protocol analysis of the design process, which states the cognitive actions and disaggregates the process to its constituent parts and segments. Eastman (1970) presented protocol analysis for the first time in this field of design research. It was conducted on the empirical work of design tasks where the designers were asked to redesign a 'utilities battery' for speculatively built premises for which they were supplied with an example of drawings and critiques from different clients. A procedure to create the protocol was developed in this course of work to collect data, record activities and verbal and non-verbal utterances, and process analyses for the designing sessions. According to these protocols, Eastman was able to address the ways the designers explored the problem and the solutions that were generated. However, no clear line was drawn between 'analysis' and 'synthesis' at this stage; rather the strength of these protocols was that we learnt about the 'nature of the design problem' and the 'range of possible solutions'. Despite the fact that some parts of that design problem were already clearly stated according to the clients' critiques of the provided example, designers were able to discover much more about the problem as they evaluated their own solutions through the design process.

2.5.1 Empirical Models Based on the Epistemology of Design Practice

Darke (1979) outlined the 'primary generator conjecture-analysis' model, which is a solution-oriented type. Designers initiate the conceptual idea based on a set of objectives, featured as the *primary generator*, and then reduce the set of solutions to a smaller manageable class to conjecture a solution. The solution is tested against the design requirements and further improvements can then be made.

Akin (1986) has conducted more detailed experiments to design complex buildings with experienced designers. Verbalisation and material data were recorded in a series of protocols with the aim of breaking down the design process into its constituent parts. However, Lawson (2006: 45) criticised Akin's study stating that it 'failed to identify analysis and synthesis as meaningful discrete components of design'. This criticism has been advocated through the eyes of a design methodologist. Akin, however, stated clearly that designers analyse the situated problems all the way through the process and that they generate solutions by synthesis from the early stage of the 'concept initiation'. Goals and design constraints are redefined all the way until arriving at the satisfactory outcome of solution.

Rowe's (1987) model of 'synthesis-decision' was developed based on the primary generator model of Darke (1979). It was basically developed for empirically gained evidence for interviewing architects. Lines of reasoning are detected in this model based on the 'synthesis' of the design ideas rather than on the 'analysis' of the problem. Rowe looked for the *organising principle* or *model* to direct the decision-making process. The argument was support by the hypothesis that primary generators or organising principles have influence through the whole process, which is detectable in the solution. Rowe extended his investigation by recording the 'tenacity' and 'persistence' with which designers adhere to major design ideas in spite of apparently insurmountable odds and unsolvable problems. The results of this investigation indicate an interesting point that such ideas that create difficulties are not rejected more readily. However, if the designer manages to overcome those difficulties, the early anchors can then be reassuring and act as creative endeavours. The designer's expertise plays a vital role in building the concept on a practical appropriate primary generator in order to avoid major problems that could have severe implications impeding the process thereafter (see Figure 2.8 for Rowe's model).

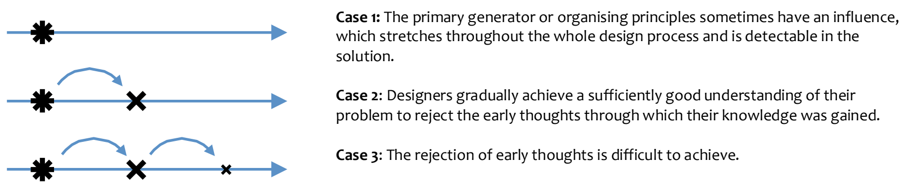


Figure 2.8 Rowe's model (1987)

2.5.2 Schön's Reflective Practice and Derivative Models

Dewey (1933) was among the first to identify 'reflection' as 'a specialised form of thinking'. He considered reflection to stem from doubt, hesitation or perplexity related to a directly experienced situation. Dewey argued that reflective thinking moved people away from routine thinking/action guided by 'tradition' or 'external authority' towards reflective action involving careful, critical consideration of 'taken-for-granted knowledge'. Dewey's ideas provided a basis for the concept of 'reflective practice' that gained influence with the arrival of Schön (1983), whose concern was to facilitate the development of reflective practitioners rather than describe the process of reflection *per se*. However, one of Schön most important and enduring contributions was to identify two types of reflection: '*reflection-on-action*' (after-the-event thinking) and '*reflection-in-action*' (thinking while doing). Argyris and Schön (1978) have proposed a model of learning based on perception of 'error' and attempt of 'correction'. If the correction is made on the same prevailing strategy then it becomes a 'single-loop learning' process (SLL), but if that correction requires a modification of objectives or strategies then it is a 'double-loop learning' process (DLL) employing a new framing system (see Figure 2.9).

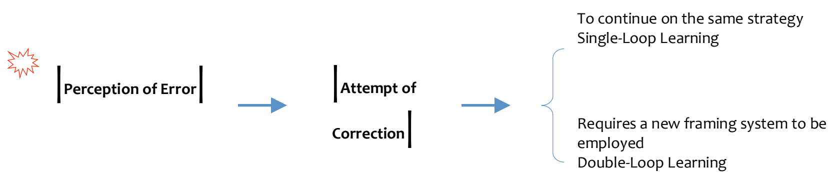


Figure 2.9 Argyris and Schön's model of learning (1978)

In 1983, Schön initiated the *reflective practice* theory as a *reflective conversation with the situation*, which is based on two concepts:

The first is 'reflection-in-action', when the practitioner connects with his feelings and prior knowledge of a certain situation within a given moment, attends to the situation directly, and simultaneously and critically responds to it, described as '*thinking on your feet*' (Schön, 1983).

The second is 'reflection-on-action', when the practitioner has the pace of action slowed down to an extent that allows the process of making sense of that action after it has occurred, learning from that experience and possibly reflecting something new on it. In this case, the practitioner analyses the reaction to a previously experienced situation, explores the reasons around, and identifies the consequences of, that action. This is often conducted through a documented or recorded reflection of that situation.

On his introduction of 'reflection-on-action', Schön considered the fact that our 'thoughts' interfere with our 'doings' as extended potential limits of the 'reflection-in-action', which contains grains of truth, but at the same time depends on a mistaken view of the relationship between 'thought' and 'action'. He stated that 'the continuity of inquiry entails a continual interweaving of thinking and doing' (Schön, 1983: 278). In our interpretation, a subconscious, time-bound, *reflection-on-action* may collide with the current, continual *reflection-in-action* of the situation, producing a sudden insight from which a new concept may result. Figure 2.10 demonstrates this interpretation of Schön's reflective practice model showing the potential collision point for the two processes.

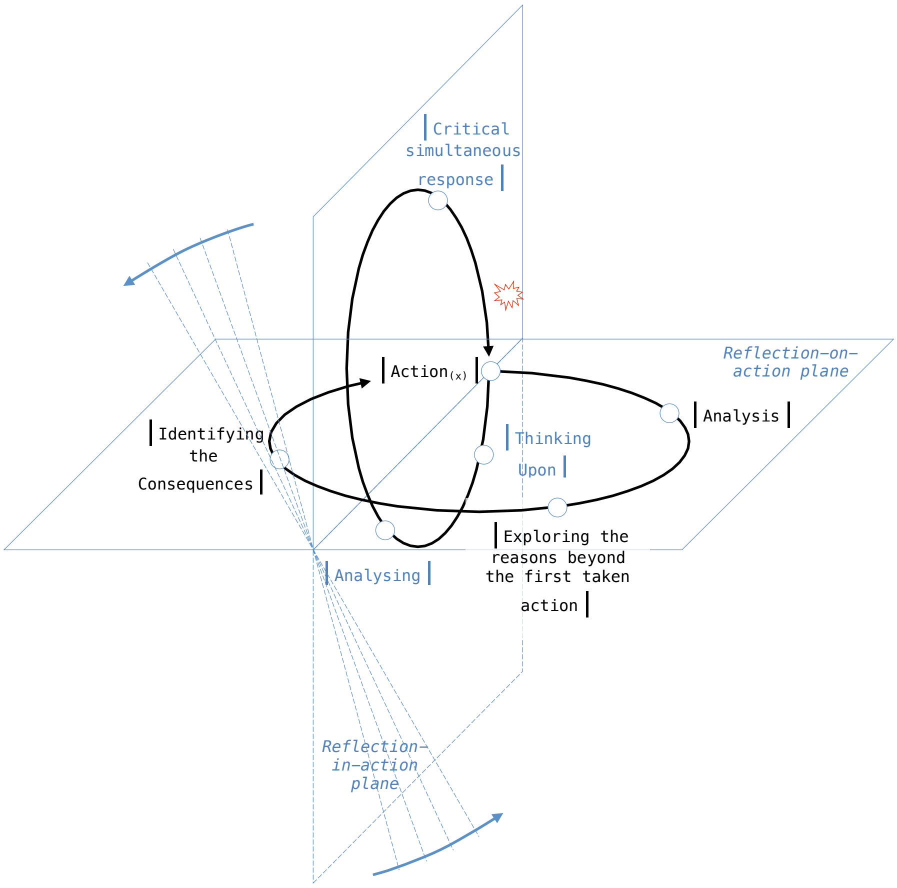


Figure 2.10 Interpretation of Schön's (1983) *reflective practice* model where insights appear due to the bi-matrix of the collisions between 'reflection-in-action' and 'reflection-on-action'

Ellmers (2006) clarified that reflection-in-action takes place when the designer is surprised by a unique situation during the process, whereas reflection-on-action involves contemplation of actions from the preceding actions. However, Eraut (1994) has raised the importance of *reasonable time*; if time is short, then the reflected decision has to be made from a rapid scope of the situation. Eraut sees this reflection as a 'metacognitive' process, in which 'the practitioner is alerted to a problem, rapidly reads the situation, decides what to do and proceeds in a state of continuing alertness' (Eraut, 1994: 145). In fact, Schön has not ignored time from his proposition, rather emphasised that pace and duration of episodes of reflection-in-action vary with the pace and duration of the situations of practice. In his view, performance in such situations depends on the practitioner's skill in 'how to think while doing' (Schön, 1983).

Schön also emphasised that when a practitioner does not reflect on his own inquiry, he keeps his intuitive understandings 'tacit' and is inattentive to the limits of his scope of reflective attention (Schön, 1983: 282). While reflection is a skill to be learned and practised, the reliance on intuition is still necessary for a creative process but is not the only condition (Ciampa-Brewer, 2011). Thus, we derive from Schön's theory that 'a creative process stems on intuition, but a designer must also be intentional about it' (Cloninger, 2007: 14). A worthwhile point is 'the need to step out the designerly way of thinking in order to control the process taking process-oriented decisions' (Reymen, 2001: 86); and 'the development of design without searching the problem space and exploring alternative solutions will stagnate the process to produce the same outcome' (Cloninger, 2007).

Kolb's model (1984) is another representative of reflection-on-action, arguing that *experimental learning* is 'the process whereby knowledge is created through the transformation of experience. Knowledge results from the combination of grasping and transforming experience' (Kolb, 1984: 41). In other words, transforming the information gained through prior experience into knowledge that can be tested and applied to the new situation. Figure 2.11 illustrates Kolb's model.

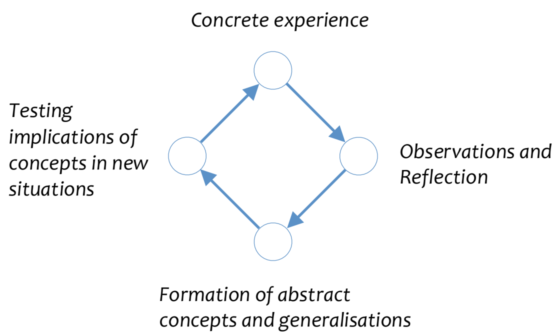


Figure 2.11 Kolb's model (1984)

2.5.3 Structured Models for Reflective Practice

A number of models have been advanced in different fields of professional practice that were developed from Schön's reflective practice. Quinn (2000: 82) suggested that most of these models involve three fundamental processes:

- *Retrospection:* thinking back about a situation or experience
- *Self-evaluation:* critically analysing and evaluating the actions and feelings associated with the experience: using theoretical perspectives
- *Reorientation:* using the results of self-evaluation to influence future approaches to similar situations or experiences.

Gibbs's 'reflective cycle' (1988) is built on Kolb's experiential learning cycle. It proposes that 'theory' and 'practice' enrich each other in a never-ending circle. This is conceived as a 'de-briefing sequence' (Gibbs, 1988: 46). This cyclic model of reflective practice has become adopted in professional education as a way to facilitate reflection (see Figure 2.12). Johns's 'structured reflection' (1994, cited in Finlay 2008) offers a reflexive approach that was criticised for 'being overly prescriptive and reductively cutting human experience into neat pieces' (Finlay, 2008: 9). Johns has revised his model over the years to learn from the 'reflection on experience' 'to offer more holistic, less mechanical elements to encourage deeper reflection' (Finlay 2008: 9). The advantages and disadvantages of Johns's model are outlined in Quinn (2000). On the positive side, the model shows how to reflect and offers comprehensive criteria, but the disadvantage is that imposing an external framework leaves little scope for practitioners to draw on their own intuitions, values and priorities.

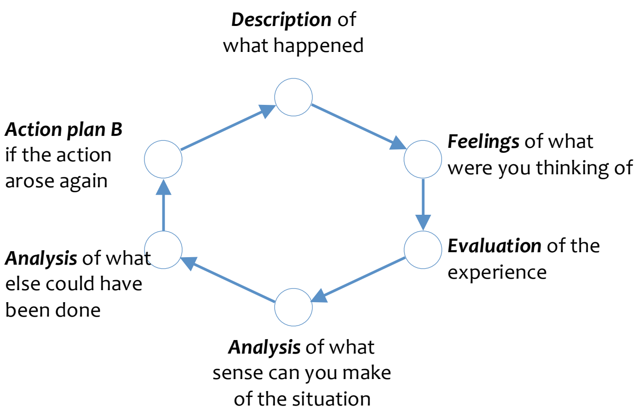


Figure 2.12 Gibbs's Reflective Cycle model (1988)

According to our readings of empirically gained models, we conclude that the *design situation* is characterised when:

- The designer cannot avoid acting: acting is unavoidable, inseparable.
- The designer cannot step back and reflect on the actions: designing in 'one go'.
- The effects of action cannot be predicted: an unanticipated phase of design.
- There is not a stable representation of the situation: the representation of design is still indefinite, indefinable and subtle.
- Every representation is an interpretation.
- Facts cannot be handled neutrally; the designer creates the situation while being in it.

Types of decisions in the design process are twofold: first, from a global view of the process, i.e. stepping back for evaluation and planning ahead conceptual strategy; and second, from a local view based on a simultaneous perceived action of the design situation. The former type is process-driven while the latter is content-based (see Figure 2.13).

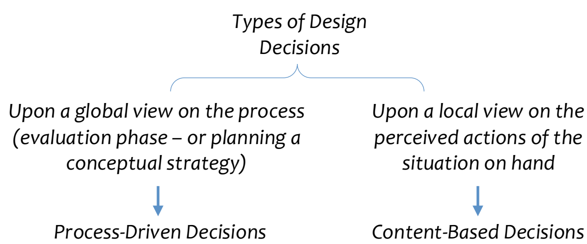


Figure 2.13 Types of decision-making in the design process

2.6 Models of Evolutionary Design Process

This section discusses two significant models that represent the concept of *evolution* while looking at the design process. The first model is the 'function-behaviour-structure', known as the 'FBS' model, which was developed in a series of studies over the years (Gero, 1990; Hybs and Gero, 1992; Gero and Kannengiesser, 2004), and the second is the *co-evolution* model (Maher, 2001; Maher and Tang, 2003).

2.6.1 'Function–Behaviour–Structure' (FBS) Model

The FBS model adopts a technical rational approach to learning to undertake Alexander's concept of '*fitness*' (1964) to present the relation between the *form of product* and its *context* (refers to the *environment*). Hybs and Gero (1992) used the concept of biological evolution to propose the FBS model. Hinging on the principles of *cross-over* and *mutation* for creating *genotypes*, sources of *novelty* can be manipulated, randomised, and diversified accordingly.[18] Gero and Kannengiesser (2004) developed this proposition and inferred that the model is a 'situated' framework of the design process. The FBS map of design process described the design *novelty* as:

> The design process is nothing more than selection, refinement, modification and combination of existing designs or objects considering the current performance requirements and constraints. This is diametrically opposite to the former view. It assumes an intrinsic evolutionary process in design where any novelty, even a so-called innovative or creative design, is a result of recursive steps of generation and evaluation and where each new solution is based on pre-existing solutions (Hybs and Gero, 1992: 274).

Through this analogous view of *natural evolution* as an evolutionary design, this model stems from evolutionary-style processes of *cross-over* and *mutation* to introduce the 'genes' of design and 'inheritance' from one generation to the next. According to Hybs and Gero (1992), the following principles are forwarded for the FBS model:

1. A designer is anyone engaging in *intentional*, *purposeful* activity with the aim of devising a description (plan) for a product or artefact.

2. Design solutions have often been seen as results of a *sudden* insight, *inspiration* or *intuition*.

3. Design process is a matter of *recursion* in that *novelty* is based on recursive steps of generation and evaluation processes and that each new solution is based on 'pre-existing' solutions (see Hybs and Gero, 1992: 274).

4. Design is a 'cyclic' process the process implies a cyclic iterative procedure. Likewise prescriptive models, it deals with '*refinements of design*', '*goal specifications*', and '*optimization of solutions*' (Hybs and Gero, 1992: 274).

5. Design models must take into account the *environment* and *context* that the final product performs and deals with, essential to the reality of the design process. Various environmental factors are introduced into the design's representations to test and optimise the product with the context:

> Some of those tests are carried out on preproduction versions, which are exposed to real operating conditions, and changes are often made to the final design as a result of its performance in these tests (Hybs and Gero, 1992: 275).

6. Analogous to *neo-Darwinism*: searching for a suitable metaphor for the design phenomena in other domains, e.g. '*biological evolution*' model – a mechanism of development for the design process:

> The process of biological evolution as first formulated by Darwin and more recently by neo-Darwinists could give us a powerful analogy for the development of a model of the design process and methodology based on the mechanism of natural evolution and selection (Hybs and Gero, 1992: 275).

7. The FBS aims to produce a 'plausible' model that would explain the complexity of design process included in the early phase.

> The problem here is how to produce a plausible model which would explain the design process in its complexity including its early phase. This model should be understood rather as an explanation of an abstraction rather than the description of a reality (Hybs and Gero, 1992: 275).

[18] See Appendix 2.1 for detailed discussion on the *function-behaviour-structure* model, clarifying the principles of *cross-over* and *mutation* and the role on *novelty*.

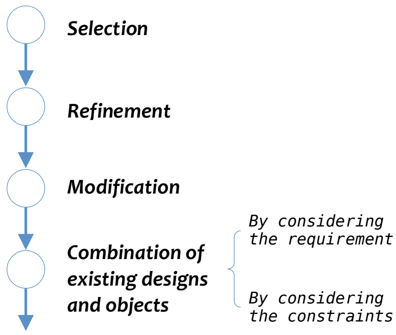


Figure 2.14 Hybs and Gero model (1992)

The FBS model was developed over the years through John Gero and his research group. When Dorst and Vermaas (2005) critically analysed the FBS model of designing, focusing on its internal clarity and external empirical validation, they showed that at least two different versions of the model can be distinguished, which raised fundamental questions about the precise location of the transition between '*structural*' and '*intentional*' descriptions of artefacts and the empirical status of the model as a whole. Dorst and Vermaas concluded the following:[19]

First, concerning the internal clarity of the FBS model, the definitions of the concepts function, behaviour and structure of artefacts have changed in at least two different versions of the FBS model (Dorst and Vermaas, 2005: 24).

Second, concerning the external validity of the FBS model, Dorst and Vermaas pointed at the Delft protocols (1996) as a significant event in the area of design research that does not support an empirical validation for the FBS model, if it is taken as factual description of design.[20] However, they stated that the model could be a valuable starting point for theory development and tool development (Dorst and Vermaas, 2005: 25).

In our empirical work on architectural case studies, the changes of definitions through the development of the FBS model have made it unclear how to code the dependency relations between the emergent actions in the architectural design processes. Neither the 'cyclic' nature of the evolutionary stages nor the definitions of function, behaviour, and structure can be generalised in every design process. Each design step occurring in the structure of reasoning stems from the context of a highly complex configuration according to several factors and variables. This drives our research towards adopting empirically gained evidence that is based on describing the context where the design action stems from.[21]

2.6.2 Co-evolutionary Design Model

This computational model, introduced at first by Maher et al. (1996, 2001) and Maher and Tang (2003), adopts the rational technical approach of looking at design as a '*search process*', based on the Simonian interpretation (Simon, 1969) – like the versions of the FBS model. This model assumes two parallel searching (notional) spaces that exist in any design process: the *problem* space and the *solution* space.

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[19] Out of several papers of the FBS model, Dorst and Vermaas isolated three studies that were considered important milestones towards the development of the FBS model: Gero (1990); Rosenman and Gero (1998); Gero and Kannengiesser (2002).

[20] The *Delft protocols* is a significant *design* research event where key researchers presented several studies on two design case studies for 'individual' versus 'located collaborative' design processes. A variety of protocol studies were applied to the cases leading to significant methodological and content-based outcomes. For more on those research studies, see Cross, Christiaans and Dorst (1996).

[21] In Chapter 4, a schema of qualities is developed and presented while evaluating several attempts to segment and code the design process of several pilot studies into meaningful structure of reasoning. One of the most crucial points in this study (in association with the quantitative analysis of linkography networks) is to adjust the level of segmentation the design process is dichotomised to in order to avoid any trivial or un-meaningful events that show insufficient results.

The conception is that the designer searches each space iteratively, using one space as the basis for a *fitness* function while using the other to evaluate the emergent action, and vice versa. This model asserts that there is a sort of *transformative* relation between the two notional spaces (see Figure 2.15).

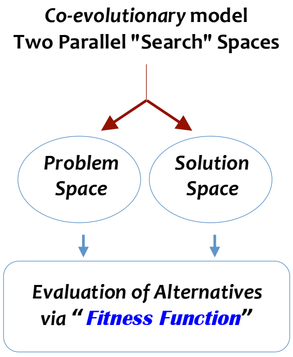

Figure 2.15 *Co-evolutionary* model
Source: Maher (2001); Maher and Tang (2003).

Maher and Tang (2003) argued that the co-evolutionary design model can be developed to become a cognitive model with the purpose of characterising the way designers iteratively search for a design solution, making revisions to the problem specification. This perception emphasises the hypothesis that the design cognitive process is considered cyclic where the effect between the notional spaces is iterative and periodic. It looks for evidence of the co-evolution between *problem specifications* and *design solutions*. An assumption of a direct correlation occurring between the *computational* and *cognitive* models, on the *co-evolutionary nature* between the *problem* and *solution* spaces, exists provided that both spaces complement each other, having strength in different aspects of the design process.

2.7 Creativity in the Co-evolution Design Process

Dorst and Cross (2001) investigated creativity in the design co-evolution of the *problem-solution* process and came up with interesting results on this application of the co-evolutionary design model:

1. The problem and solution spaces co-evolve together with the interchange of information between the two spaces.

To express the case of the 'creative' event, a rough description of what happens in the event is that a chunk, or seed, of coherent information is formed in the assignment information that helps to crystallise a 'core' solution ideas. This core solution idea changes the designer's view of the problem.

2. The 'change' is formed in correlation with the information provided in the design brief (functional programme). This is aligned with Penn's definition of the design process:

> Process is one of co-evolution of the design and the brief with the one stimulating the other iteratively … At the end of the design process, one should have developed both a design and a relatively well-stated brief. (Penn, 2008).

3. Observing designers 'redefining' the design problem, investigating whether the problem 'fits in' with earlier solutions, is often followed by a 'modification' process on the present fledging solution. In support to the co-evolutionary model, Dorst and Cross stated that the pattern of development can be modelled quite clearly along the lines of the Maher et al. model (1996).

Referring to Dorst and Cross's conclusions based on the application of the co-evolutionary model observing creativity in several design processes, figures 2.16, 2.17, 2.18 and 2.19 demarcate the co-evolutionary relation between the problem and solution, illustrate the consecutive stages of design; starting from the early proposition, passing through crystallising the core solution during the co-evolutionary process and information provided between the notional spaces, and finally ending with the modification of a final solution.

4. Co-evolutionary process consists of the following consecutive stages:

   - Designers start by exploring the problem space [PS] and find, discover, or recognise a 'partial' structure [$P_{(t+1)}$] that is then used to provide them with a partial structuring of the solution space SS [$S_{(t+1)}$].
   - They consider the implications of the partial structure within the solution space, use it to generate some initial ideas for the form of a design concept, and thus extend and develop the partial structuring [$S_{(t+1)}$]. Some of these developments of the partial structuring could be derived from references to earlier design projects.
   - Designers transfer the developed partial solution structure back (reverse processing) into the problem space [P(t+2)], and again consider implications and extend the structuring of the problem space. Their goal is to create a matching 'problem-solution' pair.

5. The *emergent bridges*, *frames*, *recognition*, *defaults*, *surprises* and the *creative event*:

   - *Emergent bridge*: Dorst and Cross's (2001) observations confirmed that creative design involves a period of exploration in which problem and solution spaces are evolving and are temporarily unstable until the reformulation of an emergent bridge that identifies a 'problem-solution' pairing.
   - *Problem framing*: A creative event occurs as the moment of insight at which a problem-solution pair is 'framed': so called 'problem by framing' (Schön, 1983). Framing ability is a skill of the creative designer, Dorst and Cross argued. Cross and Clayburn Cross (1998) conducted studies of outstanding designers and suggest that this 'framing ability' is crucial to the high-level performance in creative design. Asking *how do designers 'frame' the partial problem*? Dorst and Cross (2001) observed recognition of a cluster of related information in the problem.
   - *Recognition*: This enables the designer to make a partial structuring of the problem space, clustering the related and coherent information. A procedural strategy is observed where designers search through the information, ask a quasi-standard set of questions, and propose a set of expectations about the answers to these questions.
   - *Defaults*: These expectations are considered the *default* project until passing through several stages in which the challenge of design is compared.
   - *Surprises*: The pertinent information to the assignment is compared with the outcomes to build a general image and look for surprises.
   - *The creative event*: occurs according to the following motivations:

     - Losing the *coherence feed of surprising information*: this is linked to coherent cluster chunk of information that simplifies the problem.
     - The recognition of this simplification happens suddenly and is experienced as a *creative insight*.
     - The coherence between interesting information items drives the designer to have the feeling that he or she has grasped the core of the problem.
     - The idea to be seen as being *original* while it is not; known as the '*false Aha!*' (Dorst and Cross, 2001). Simple obvious selection and combination of information leads to the same core idea.
     - The transformation of the problem chunk into a solution turns out to be simple. The designer has to turn the problem around to arrive at a solution that often relies on this reasoning path.
     - The 'creative' aspect of design can be described by introducing the notions of 'default' and 'surprise'. According to Schön (1983), the notion of 'surprise' in creative design has the pivotal role of being the impetus leading to 'framing' and 'reframing' of the 'problem-solution' relation.
     - 'Surprise' is what keeps a designer from 'routine' behaviour. Creativity in the design process can validly be compared to such 'bursts' of development.
     - The 'surprising' parts of a problem or solution drive the 'originality' in the design process.
     - The 'process of evolution' can be seen as being driven by a reaction to a 'surprise' (change in the environment) rather than a 'gradual changing' of a 'phenotype' and 'genotype' in an ever-closer approximation to an optimum in the 'fitness function' (Dorst and Cross, 2001).

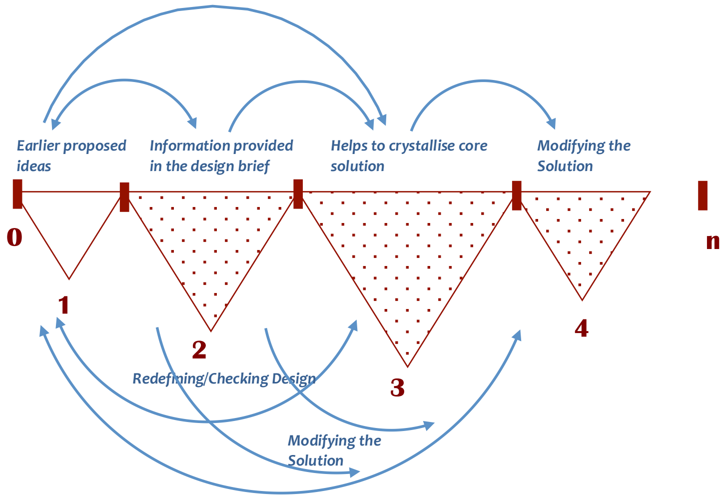

Figure 2.16 Interpretation of the stages of design process
Source: Adapted from Dorst and Cross (2001) based on Maher et al. (1996).

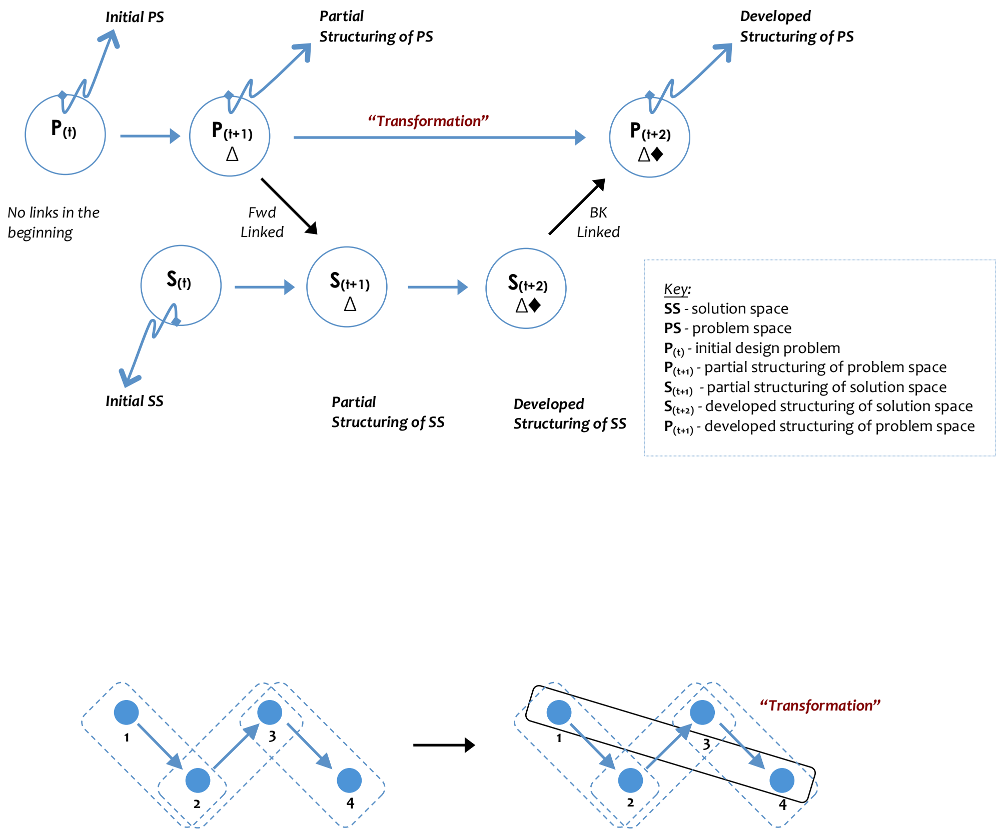

Figure 2.17 Co-evolution model
Source: Adopted from Dorst and Cross (2001) based on Maher et al. (1996)

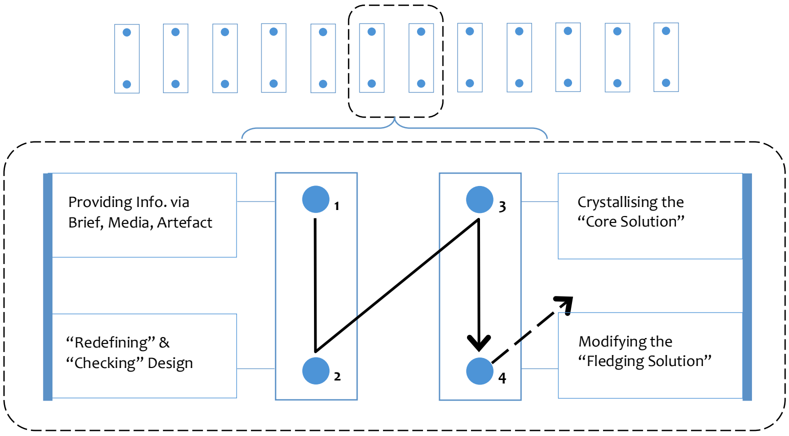

Figure 2.18 Stages of co-evolution process between the two notional design 'spaces': problem space and solution space
Source: Maher et al. (1996).

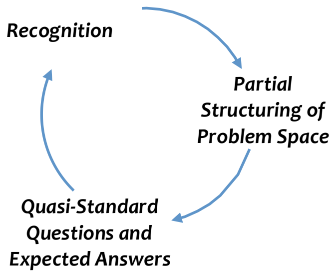

Figure 2.19 Designers pose questions as well as expectations
Source: Dorst and Cross (2001).

2.8 In Conclusion

Many attempts have been made to understand the nature of design processes. The long literature of design paradigms and models signifies those endeavours and aims at the same time to argue which is more appropriate to understand the formation of concept in creative discovery – either to describe the contents in the situation or to prescribe the decisions and stages in the process. Our intention is not to test a certain model or method of analysis against empirical data. Rather, this chapter shows the importance of shedding light on the variety of models, controversial views and research directions while we pursue the investigation of design processes and creative discovery. The literature is immense and our objective is to consider those views and propositions to analyse the design process.

Adopting empirically gained evidence as a methodology has an effect on determining the role of reflective practice (between the designer and his/her tools and interim artefacts) that would show us the emergence of sudden insights and formation of concepts and their role in turning the direction of thought or structuring it. Deducing the creative qualities for the structural units of reasoning and the phenomena associated with creative discovery urges us to observe and identify the role that each design step, move or segment plays in the design situation, on the one hand, and in the formation of reasoning, on the other. Therefore, in support to this argument, ethnographic observations of empirical studies can be seen as enriching our investigation and interpretation processes. One particular point to consider is that those views and models interpreting the nature of design have overlooked the importance of identifying what a *segment* of design is, what a *critical action* is, and what a *creative eureka insight* is.

We consider it is more important to detect the structural units of design precisely if our intention is to consider aspects of the design situation in order to capture the actions that affect the design process than the technical rational approach that this chapter has emphasised. Serious attempts have been proposed from Goldschmidt (1990, 1991), Gero (1990), Hybs and Gero (1992), Gero and Kannengiesser (2004) and Kan and Gero (2005a, 2005b, 2005c, 2008) and we have considered diligent methods to identify the ‘design move’ or ‘surprising moment’, but we will show in Chapter 4 the incompleteness implied by those descriptions and that they do not fit together if we seek to build a joint model. However, Donald Schön’s claim of *reflective practice* as the main foundation to interpret the design process and describe the situation is closer to reality in our opinion. This theory reveals the insights coming out of the ‘reflective conversation with the situation’ and grasps the structure of thinking that we can rely on in constructing the linkographs. Structured models provide comprehensive criteria of the design process and urge researchers to learn how to reflect interpretations in the same structured way, but they are criticised as imposing an external framework, which leaves little scope for the practitioner (researcher) to draw on his/her own intuitions from observations.

Our research epistemology relies on an inductive exploratory approach, not to test a certain hypothesis according to any of those presented models, and we seek to draw conclusions out of the observation of the phenomena; the theory emerges from the phenomena, not the reverse. The intention through the detailed presentation in this chapter has been to present the *state of art*; the rules and foundations that have been implied to draw findings on what design is. In the following chapters, we will clarify the nature of design processes to show that the empirical inductive approach offers the means of ‘analysis’, ‘segmentation’ and ‘coding’ rather than adopting the hypothesis-testing approach that might force the collected data towards testing a specific hypothesis. This inductive approach deals with the complexity of design process and the involvement of multiple variables.

2.9 Key Findings of Chapter 2

- There are a variety of methods to analyse the design process and deconstruct it into structural units of reasoning. While the technical methods prescribe cyclic stages of the design process, the practitioner’s method describes each action emerging. The procedural models present design as a series of stages, each of which is visited only once by the ideal process.
- The empirical approach allows us to monitor the associated activities with the generation of creative ideas, while structured methods force the practitioner to apply certain criteria but undermine the practitioner’s scope for deriving his/her own intuitions.
- Understanding the phenomenon associated with the formation of novel concepts is pertinent to observing the emergent actions on the situation level, which can be achieved through empirically gained evidence.
- Diversifying the definition of design briefs and conducting experiments on architects with different backgrounds and expertise would test the reliability of segmentation and coding methods and assure the internal and external validation.

Chapter

3 Research Methodology

This chapter introduces the methodology and research process. It identifies the significance for the research problem of adopting an investigatory approach to search for the formation of concepts and phenomenon of sudden mental insights in architectural design processes. Inductive methodology is adopted to collect data, to search through the complexity of the variety of factors and variables involved in the design processes.

It outlines some pilot experiments conducted to test the research parameters over different experimental settings, e.g. tools, software applications (conventional, parametric or generative), types of briefs (specified with conditions or unspecified), settings (solo or collaborative) and a variety of projects. It illustrates the gap in research to detect the critical actions (eureka and aha! moments) and the qualities of creative actions by using the existing protocol methods in those experiments.

It presents the significance of bridging the gap between quantitative and qualitative approaches from different research areas and empirical studies for a methodological development to describe the formation of novel concepts in the design processes. The aim is to capture the creative actions, identify the episodes, segments of moves, and sudden eureka insights that take place in the design process.

The main aim of this dissertation is to detect the nature of design processes to unveil the phenomena associated with creative discovery, by observing how ideas and novel concepts evolve in a number of design experiments conducted with different architects. Two controversial points are identified: first, the relation between the *contents* (design products) and the *structure of reasoning*; and second, the significance of the emergence of sudden mental insights that could affect creativity in the design process. In describing various experimental design cases, this research will review some of the predefined *segmentation* and *coding* models defined in the literature of design studies in Chapter 2, to look at the drawbacks and develop an objective analytical tool. The validation of this tool will be verified through the application and coding of different design cases to ensure its reliability.

This study implements mixed research methodologies for a number of reasons. On one side, it *tests the hypotheses* of predefined schemes of segmentation and coding, in particular: Goldschmidt's identification of *what design move and critical action are,* and the *link index* method that associates creativity with 'richness' and 'productivity' (1990, 1991); Gero's *function-behaviour-structure* FBS coding model (Gero, 1990; Rosenman and Gero, 1998; Gero and Kannengiesser, 2002). Kan and Gero's quantitative method, which identifies creative insights and the application of Shannon's entropy in linkography protocols (2005a, 2005b, 2005c, 2008); and Suwa et al.'s macroscopic cognitive scheme to identify the cognitive actions in the thinking process (1998a, 1998b).

On the other side, it adopts an *inductive* approach to collect empirical data unprejudiced by hypotheses to develop appropriate segmentation and coding schemes and investigate the nature of the design process and creative discovery. By unfolding the structure of the dependency relations between design actions in the reasoning process, we aim to reveal how ideas intervene to form concepts and whether creative insights emerge accordingly. By identifying the role of creative insights in the structure of reasoning, we aim to derive a taxonomy of qualities for the creative actions in the design process.

3.1 Design Complexity and Multivariable Processes

Given the complex nature of design processes, which consist of multiple variables, being able to adopt a *controlled experiment* approach to test the effect of certain *variables* may seem difficult or even impossible. Many attempts to deploy the logical-deductive approach to investigate creativity in design processes have been introduced by researchers, particularly from the technical rational paradigm; for example: the occurrence of mental insights in *insightful* problems has been investigated for the 'nine-dot puzzle' (Weisberg and Alba, 1981); the role of *freehand sketching* tool has been contrasted with *3D virtual world* (Gül and Maher, 2006a, 2006b); the pattern of *problem framing* has been studied in different design settings – paper-based versus digital-based settings (Kvan and Gao, 2006); the behaviour of *design collaboration* has been tested in *remote-sketching* against *three-dimensional virtual worlds* (Maher et al., 2004a; 2004b; Gero et al., 2004). These are samples of studies that adopted the logical-deductive methodology for hypothesis testing to deduce the final outcomes. However, while attempts in those experiments were made to control certain variables in two opposite modes of *absence* versus *appearance*, the final results could have been affected by other undefined variables, which might affect the clarity and accuracy of the final outcome of the research.[22]

Confounding variables may affect our investigation into the nature of design processes and observation of the phenomena associated with creativity. The impact may affect the elements under investigation, i.e. the emergence, decision-making and reasoning structure. Taking the variable of 'familiarity with using design tools', for example, most architects prefer to switch back and forth between different tools while designing to avoid attachment to a particular presentation of an idea, which may end up causing a fixation effect. Multiple switches between tools and representations are idiosyncratic characteristics that most architects have and grow through practice. The variety of tools allows different patterns of designing: sketching, digitising and re-sketching (between paper and CAD), generating forms in two and three dimensions, physical modelling, and scripting. The advanced technology of design tools has provided various options to represent our mental thoughts. In recent years, the use of digital fabrication technology has become a trend in evaluating the interim products of stages of concept development. Providing the generative, parametric and generative application of design software has also enlarged the possibilities for architects to set up their own idiosyncratic way of designing and modelling. Which takes credit for the 'authorship of novelty' – the architect or the tool? – is an implication of the technological advancement and reliability of computational techniques in design as well as in construction processes.[23]

The distribution of cognition between the architects in design collaboration is another crucial factor that relates to the mental and physical representations of ideas in the thinking process. Hutchins (1995) claimed that knowledge and cognition are not confined to the individual; rather, cognition is distributed by placing memories and facts or knowledge on objects, individuals or tools in our environment. Therefore, the distribution of cognition in the design process has three aspects: distributed across the members of a social group (reflection-in-action); distributed in the sense that the operation of the cognitive system involves coordination between internal and external cognitive structures of representation;[24] or distributed across time so that the products of earlier events may transform the nature of related events, e.g. linking ideas back and forth between sketches, or transforming the design concept by drawing several projections.

In design collaboration, *authorial control* and allocation of *creativity authorship* are dependent on the collaborators' expertise and leadership: who is 'leading' and who is 'following'. Craig and Zimring (2002) pointed out that variation in the expertise and background of the collaborators results in more variation in the fixation effect, while similar experience gives almost the same fixation effect.[25] The design process is affected by a spectrum of confounding differing variables in ways that may significantly vary from one case to another. It is therefore complex and multivariate in a way that makes the isolation of those variables in controlled experiments very difficult. This supports, therefore, our intention to adopt the epistemology of practice in this research to describe content-based actions and decisions in the empirical study of procedural and contextual components in the design process. Table 3.1 lists some variables that may affect creativity in the design processes.

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[22] There is more information on those experiments in Appendix 3.1. The attempts were oriented towards presenting the cyclic nature of the design process in those studies.

[23] Theodoropoulou (2007) introduced the 'authorship of novelty in generative design' where she presented an interesting study on 'designing with CAD', 'designing with programing', and 'designing with a self-organising system' for two different categories: the 'architect-user' and the 'architect-programmer'.

[24] Cognitive structures are the basic mental processes people use to make sense of information (Garner, 2007). The term 'cognitive structure' was first coined by Jean Piaget (1896–1980), who was best known for his work on the development of human knowledge. He believed knowledge was constructed on cognitive structures and that humans develop their own cognitive structures through schema by accommodating and assimilating information (see Campbell 2001).

[25] Venn diagrams can be deployed to present the relation of expertise and background between collaborators. A Venn diagram or set diagram (conceived around 1880) is a diagram that shows all possible logical relations between a finite collection of sets.

Table 3.1 Examples of confounding variables involved in the investigation of creativity in design processes

	Possible Confounding Variable	Subject of details
In individual design settings	***Design settings***	Co-located versus remotely-located settings
	Design tools	Sketching, 3-D physical or graphical models
	Design applications	Conventional, parametric or generative
	Design media	Paper sketch, whiteboard, 2-D/3-D software, programming applications
In collaborative design settings		
	Designing platform	Specific sharing applications or desktop-sharing
	Collaboration typology	Executional, communicational, visual
	Communication types	Unstructured verbal discussion, text based communication, graphical communication
	Presence	Face-to-face or non-presence (virtual/hypothetical)
	Timing of collaboration	Real time synchronous or asynchronous presence
	Expertise	Background, years of experience, design trends
	Design task	Identifying the nature of the design task, generative or traditional
	Participants/designers	Expertise, familiarity in using certain design applications

The aim of outlining this complex nature of design processes is twofold. The first is to state the research methodology and appropriate approach to investigating the phenomena of creative discovery in design processes. The second is to consider the variety of design tools and applications in the outline of pilot experiments and primary case studies in order to observe as many diverse situations as possible in the experiments to assure the reliability and validation of the empirical work and draw conclusions from a wide sample.

3.2 Research Methodology

In trying to capture the structure of reasoning and understand its relation to the evolution of ideas and emergent artefacts in different design processes, it is difficult to control all the multiple variables involved. This research adopts mixed research methodologies for two reasons. (1) It adopts an inductive approach to collecting empirical data for various settings of design processes without prejudice from any suggested hypotheses in advance in order to observe the phenomena associated with creative discovery. (2) It tests the existing segmentation and coding schemes of protocol studies while describing the creative events that take place in the design experiments and looks at the advantages and disadvantages of using any of those schemes in our analysis and descriptions. If any of the suggested schemes in this field of research assures validation and reliability for coding our pilot case studies, it can be justifiably taken forward to the next stage of final case studies. Otherwise, we identify the drawbacks and design a reformed version for segmentation and coding that would more or less reflect our indicated observations on those design processes. The next section looks at the differences between inductive and deductive research methodologies and identifies the nature of application for each approach.

3.2.1 Deductive Approach

In the deductive approach, a hypothesis (or hypotheses) is identified at the beginning of the research, a strategy is designed to test this hypothesis, and a conclusion (or conclusions) is deduced from propositions. The emphasis is generally on causality, while inductive approaches usually focus on exploring new phenomena or looking at previously researched phenomena from a different perspective. When a deductive approach is followed, a set of hypotheses is formulated and tested. Through the implementation of relevant methodology, the formulated hypotheses will be proved right or wrong. 'The reasoning starts with a theory and leads to a new hypothesis. This hypothesis is put to the test by confronting it with observations that either lead to a confirmation or a rejection of the hypothesis' (Snieder and Larner, 2009: 16) In some cases, it will lead to a new hypothesis, which will be confirmed or proved false as result of the research.

3.2.2 Inductive Approach

The inductive approach moves from specific observations to broader theories. From these observations patterns can be identified and a hypothesis developed. If the observations continue to confirm the hypothesis it becomes a theory. No theories apply at the beginning of the research and the researcher is free to alter direction for the study. 'The inductive approach "essentially reverses the process found in deductive research" (Lancaster, 2005: 25) and, specifically, no hypotheses can be set at the initial stage when the nature of the research is blurred and ill-defined'.[26] 'Inductive reasoning is often referred to as a "bottom-up" approach to knowing, in which the researcher uses observations to build an abstraction or to describe a picture of the phenomenon that is being studied' (Lodico et al., 2010: 10). Thus, in inductive studies no known theories, hypotheses or patterns need to be tested during the research process.

The grounded theory is a simplified version of inductive methodology. *Grounded* theory (GT) is a qualitative research methodology that generates theory from data '*bottom-up*'; however, the research process is more structured than in inductive studies. Glaser and Strauss were first to introduce grounded theory in 1967, which ever since has been widely implemented in social science research to investigate phenomena that are intertwined and tangled with multiple entities. The theory operates in a reverse fashion from the traditional logical-deductive methodology and is structured by the following steps. It begins with data collection followed by a coding process where the key points are marked with a series of *codes*, which are extracted or concluded from the first observations. Codes are grouped into similar concepts in order to make them more workable. From these concepts, *categories* of data are formed, which are considered the basis for the emergence of theory. *Properties* emerge for each category of data through the method – knowing that categories and emergent properties keep changing for modifications through the process as results of theoretical sampling.

Data collection → Coding → Grouping → Categorising Properties → Concepts → Hypothesis → Testing → Verifying/Generating the theory

One goal of grounded theory is to formulate hypotheses based on conceptual ideas. A researcher can try to verify the hypotheses that are generated by constantly comparing conceptualised data on different levels of abstraction, and these comparisons contain deductive steps. Thus, grounded theory enables the researcher to use a constant comparative method in order to examine and compare every emergent concept to draw out new concepts that have not been thought of before.

3.3 Research Design

Our research adopts an exploratory approach that aims to gain evidence from empirical work. The research process is divided into the following sets:

First, an inductive approach is adopted to collect data. This is overlaid with our ethnographic observations on emergent activities and with the designers' retrospective comments.

Second, the deductive approach takes part in the evaluation of the existing segmentation and coding schemes to identify the advantages and disadvantages. Four particular schemes are evaluated in our research study: Goldschmidt's definitions of design *moves* or *critical actions* based on the *link index* method that associates creativity with *richness* and *productivity* of ideas' (1990, 1991); Gero's *function-behaviour-structure* FBS coding model (Gero, 1990; Rosenman and Gero, 1998; Gero and Kannengiesser, 2002); Kan and Gero's quantitative method, which identifies creative insights and the application of Shannon's entropy in linkography protocols based on the 'richness of links' (2005, 2008); and the macroscopic cognitive scheme to identify the design actions in the thinking process (Suwa et al., 1998a, 1998b). Those four schemes are widely adopted in this area of research to decompose the segments of design and construct the linkograph.

Third, the inductive approach follows to develop the appropriate segmentation and coding scheme for the qualities of creativity for the design actions in the design processes. Our aim is to identify

[26] http://research-methodology.net/research-methodology/research-approach/inductive-approach-2/

the segments of design and detect eureka and aha! moments in the sketching process to capture the structure of reasoning and evolution of creative ideas. Figure 3.1 presents diagrams for the deductive and inductive stages in the research process. It is noticed that some of these schemes are based on either qualitative or quantitative approaches.

In the qualitative approach, we aim to examine the following points for the existing coding schemes:

- The level of segmentation in each scheme
- The relation between richness of links and creative insights in linkography
- The ability to use a predefined scheme for segmentation and coding in various design settings.

In the quantitative approach, we aim to examine the following points for the existing methods:

- The measurement of balanced linkography networks
- The relativisation of measurements
- The detection of the critical actions and eureka moments through link index or entropy measures.

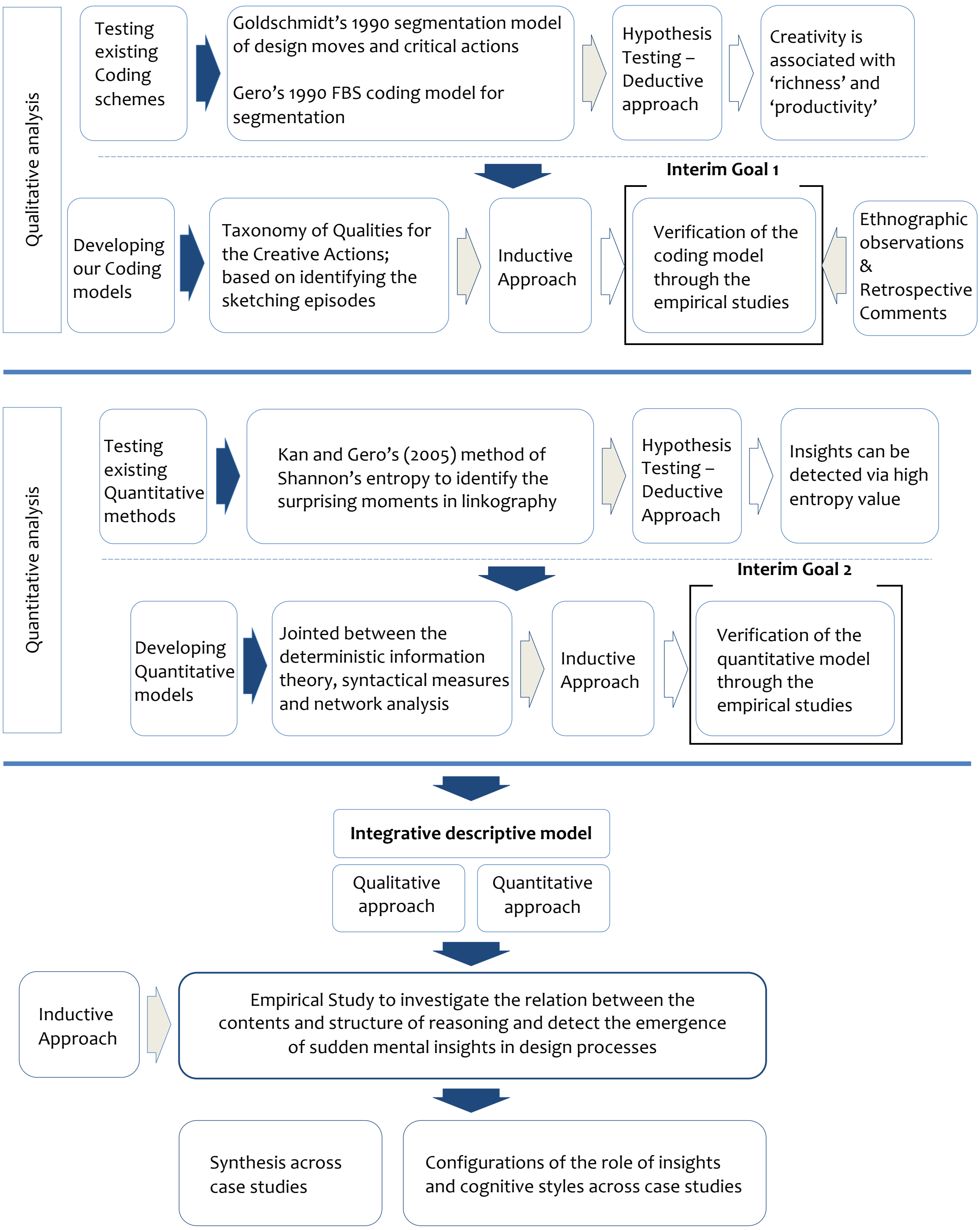


Figure 3.1 Representation diagram for the deductive and inductive stages in the research process

3.4 Ethnographic Observations

Button (2000) distinguished between two main subjects for ethnographic observations. While *ethnography* concerns the observer (ethnographer) describing what he/she witnesses, then offering an explanation of the observed phenomenon or activity in a separate step, *ethnomethodology* is a radical re-specification of the foundations that are shared by the essential ethnographers, which moves the emphasis from the production of observations (i.e. of sociological accounts and theories of social doings) to the description of accountable practices that are involved in the production of naturally organised phenomena (Button, 2000: 325) (i.e. social orders that people use according to their accounts and descriptions).

Ethnomethodology is a descriptive discipline and does not engage in the explanation or evaluation of the particular social order undertaken as a topic of study. As a method, it is used in ethnographic studies to describe people's methods that they use in everyday situations. This research, however, is not concerned with the methods that architects use in every situation but focuses on the outcome of activities. Therefore, we adopt classical ethnography to observe those emergent activities in the design process, and then offer an explanation of the phenomena that are associated with the evolution of novel concepts.

For the series of design experiments, the early stage of design thinking is under observation to understand the concept initiation process. Free rein is given to the invited architects to design freely with no intrusion from the ethnographer (observer) to avoid driving their train of thoughts towards a specific solution.

3.5 Research Process

The research process consists of the following stages:

- Stage 1: *Formulating and clarifying the research area, research topic, research question and objectives*: this research provides a bridge between design studies, creative cognition and methodological approaches to describe the design process via quantitative and qualitative methods.
- Stage 2: *Conducting a thorough literature review through utilising a wide range of relevant sources across those three areas of research*.
- Stage 3: *Critically evaluating the existing literature and pointing to gaps in the literature*: hypotheses testing – deductive approach.
- Stage 4: *Addressing methodological aspect of the study*
- Stage 5: *Choosing appropriate methodology for the research*: taking into account the characteristics of the current research and critically analysing advantages and disadvantages of all available qualitative and quantitative data collection methods: empirical study – inductive approach.
- Stage 6: *Conducting a pilot study and revising the results to assure reliability and validity*.
- Stage 7: *Undertaking primary data collection according to chosen methodology* (diversified conditions of case studies to widen the sample and assure internal and external validity).
- Stage 8: *Explaining, discussing and analysing the primary data*: turning raw data into meaningful analysis.
- Stage 9: *Presenting primary and secondary findings and other parts of the research*: building the theory bottom-up via inductive approach.

3.6 Outline of Experiments of Architectural Design Processes

Different experiments of architectural design are outlined for this explorative research. Ten design experiments are outlined according to the following stages:

First, it starts by testing 'dispersedly located collaborative design' (self-participatory: the author is participating together with a colleague in the USA) to identify the effect of the medium of online collaboration to reduce the bandwidth between the collaborators in order to facilitate the generation of ideas. Existing schemes of segmentation and coding are deployed and examined in this initial phase in order to identify the advantages and disadvantages while capturing the structure of reasoning of critical events.

Second, the evaluation of existing (predefined) coding schemes by conducting another pilot experiment to describe the activities in individual design processes. One solo design experiment is dedicated to this evaluation. The developed coding scheme is tested and re-evaluated in two different solo design experiments.

Third, the final primary experiments investigate the relation between the contents and structure of reasoning and the role of sudden mental insights, where the empirical studies of six solo design experiments are described using the developed coding scheme.

3.6.1 Design Brief

Design briefs are categorised into two types: (1) Unstructured brief to design the *Expo-Shanghai Pavilion*, 2010, and (2) Structured and specified brief with functional requirements and conditions to design the *Cheese Factory*. To gain empirical evidence on the nature of creative discovery and associated phenomena in architectural design processes, this sample of experiments is deliberately widened in order to verify and generalise our conclusions for our investigation.[27]

3.6.2 Settings for Design Experiments

- **Time**

The time allowed is one hour for each design experiment. If an architect is invited to participate in two different experiments, a period of one week is deliberately left between them to avoid the attachment of certain concepts from the preceding experiment that may affect the design process and direct the outcome towards a confounding variable.

- **Video Protocol**

All the experiments are video recorded to capture the activities and verbalisations for each architect but in a way that ensures the anonymity of the participant.

- **Retrospective Comments**

Architects are asked consequently to comment retrospectively on their concepts and stages of development to explain the transformation through the design products and for the serial order of sketches produced in the process.

- **Design Tools and Applications**

A variety of design tools are offered to the designers to use before the design process commences. Tools include conventional, parametric and generative applications, such as: freehand sketching tools, Auto Cad®, Revit®, Sketchup®, 3D Studio Max®, Rhino®, Grasshopper®, Generative Components® and Processing®. An evaluation follows to identify familiarity or propensity to use any of the applications more than the others. The advantage of freehand sketching to represent the mental thoughts in contrast to other applications has been proved in several studies (Gül and Maher, 2006a, 2006b; Kvan and Gao, 2006; Gero et al., 2004; Maher et al., 2004a, 2004b). It is used as the only tool for design in the final primary design experiments.

- **Additional Pilot Experiments**

Pilot experiments that focus on the role of the familiarity of the design tool are undertaken at the commencement of the empirical work. Eleven architects are invited to work individually to design the expo pavilion or the cheese factory in a one-hour recorded session. Those experiments vary between using a mix of conventional tools or parametric or generative software applications. Those architects are invited from wide and diverse architectural practices, expertise and educational backgrounds, with an average of 10 years' experience. A self-participatory (author plus one other) collaborative design process in remotely located settings is experimented with to design the Delft competition 'Building for Bouwkunde' (2009).

[27] All design briefs are included in Appendix 3.2.

Thus, we started by widening our investigatory approach by testing a variety of design cases that vary in their functional programmes, building types, specification and constraints using a variety of design tools. However, it was made clear that this approach involves multiple confounding variables that cannot be controlled in our observations. Table 3.2 presents the stages of experiments with design tools and design tasks. However, the following general observation are recorded while observing the activities in those experiments and also according to the participants' retrospective comments:[28]

- Parametric design is a 'process-oriented', not 'product-oriented', process. It is about setting the parameters at the early phase of concept initiation and building the following steps of design accordingly. Setting the parameters could be difficult or impossible to change or amend thereafter; especially at the end of the process, which requires high-calibre expertise in using the tool and a full comprehensive vision towards the final product ('what will it look like?') which may not be possible to imagine beforehand. Parametric design process has 'intention' that starts from the initial phase towards the end.
- Generative design has no intention as long as the generative programme generates forms, where the architect has no partial or full idea of how it will look.
- The design brief may constrain the designer from practising the capability of the generative or parametric tool, especially if it is intentionally outlined for traditional design application. However, a digital tool, whether parametric or generative, requires an advanced design brief that can cope with the capabilities of either technique, e.g. designing a wall responsive to light is quite different from designing a cheese factory.
- Among the results of explorative study, it is noticed that designers are able to generate more ideas at the initial phase of design and this ability decreases along the way to the end when a parametric or generative tool is deployed.

[28] The designers' retrospective comments are considered in order to understand the evolution of ideas and formation of concept, and the role that design tools may play while designing and developing the concept of design. These comments have complemented our ethnographic observations and recorded activities.

Table 3.2 Observations of a variety of advanced designing applications in additional pilot experiments

Exp. #	Design Tools and Media Group	Type of Design Brief	Constraints and Complexity	Participants	Design Setting
1	Freehand Sketching, CAD and 3D Studio Max app.	Specified with detailed functional requirements	TU Delft Architectural Competition 'Building for Bouwkunde', 2008	Self-participation with one other architect located elsewhere	Collaborative design
2	Freehand Sketching and Sketchup app.	Traditional/Conventional: To design a pavilion	Design brief with and without imposed constrains	Two architects	Solo design
3	Freehand Sketching, CAD and 3D Studio Max app.	Traditional/Conventional: To design a pavilion	Unstructured design brief, for familiar project, with and without imposed constrains	Three architects	Solo design
			Structured design brief, for unfamiliar project, with an imposed constraint	One architect	
4	Second Life Online platform	Self-experiments on the capability of the tool and design settings	—	Self-participatory	Solo design
5	Freehand Sketching and Eye Tracker to map the eye's glances	Theoretical based investigation on the capability of the tool	—	Theoretical Study	N.A
6	Generative tool, i.e. Processing	Free, to design an interactive tool	Design brief is free and without any imposed constrains	One architect	Solo design
7	Parametric tool, i.e. Generative Components	Traditional/Conventional: to design a Pavilion	Design brief is free and without any imposed constrains	Two architects (Author plus one other)	Solo design
8	Rhino and Grasshopper	Traditional/Conventional: to design a Cheese Factory	Design brief with and without imposed constrains	Two architects	Solo design

3.6.3 Ethical Approval

Consent forms for experimentation, video recording, assuring privacy and anonymity are presented and explained to each participant for signing before the experiment commences, clarifying the health and safety regulations in the location. Experiments are conducted under the approval of Research Ethics Department, Graduate School, University College of London (UCL), with an Ethical Approval Identification number: 2451/001. All the experiments are hosted at the premises of the Bartlett School of Graduate Studies, University College London.[29]

[29] Instructions include Health and Safety regulations of the location, introduction to the research objectives, type and setting of the experiment, and the clarification of consent forms. All forms are included in Appendix 3.2.

3.7 Research Method – Data Analysis

The research method comprises qualitative and quantitative analyses in order to analyse the data and acquire information from the linkography and recorded protocols of the design experiments. We aim to develop an integrative framework of analysis in order to assure the reliability and validity of the descriptive methods to describe the emergent events in the design processes. This integration will offer a multitude of descriptions for each critical action occurring in the design process, and thus helps us to refine our coding scheme and detection of sudden mental insights and eureka and aha moments. The following points disclose the main differences between quantitative and qualitative methods, which can be investigated while developing our methodological approach:

First, the concept of a quantitative approach is to quantify the chunks of links in the linkography networks through different measurements so as to reveal the depth in the structure of relations between actions. However, this research introduces and correlates between different types of measurements that are first introduced to the field of protocol analysis and linkographs. It includes deterministic information measurements (i.e. complexity, entropy, information content), network analysis (i.e. centrality measures) and syntactical analysis (depth measure). Each component can be computed for each event occurring in the network of relations. The complexity of design processes is multilevelled and the characteristic of depth is an important aspect to reveal the structure of reasoning and relations between actions. On the other hand, the concept of the qualitative approach is to describe the design situation by judging the transformation of concept from one situation to another while comparing the interim artefact of sketches and activities together. This helps to reveal if a drastic change occurs through transformation.

Second, quantitative methods and measures are universal for the set of data, such as finding the correlation and mean points for the whole data set; whereas in qualitative research each case study is approached individually.

Third, the research finding can be illustrated in different ways: in the form of tables and graphs in the quantitative approach, and descriptions in the qualitative approach.

The quantitative and qualitative approaches of our methodological development are concerned with protocol methods. Protocol analysis has received special attention from researchers in this field with the aim of revealing design activity (Ericsson and Simon, 1993; Cross et al., 1996). It could be deployed to investigate the nature of design process through the perspectives of 'content-oriented' or 'process-oriented' decisions, either to reveal the role of actions in the design situation (i.e. what designers see, attend to, think of, or retrieve), or to describe the process in terms of a general taxonomy of problem-solving (i.e. strategies, goals, problem formulation) (Dorst and Dijkhuis, 1995) (see Figure 3.2).

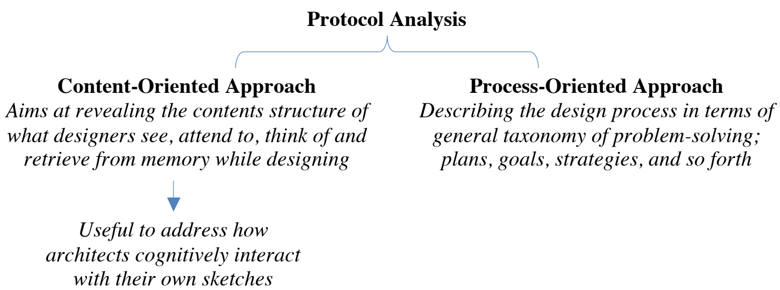


Figure 3.2 Protocol analysis classified as *process-oriented* and *content-oriented* approaches

Protocol analysis is an observational method that is suggested to monitor the designer's activities and cognitive actions through the design process. Since design processes comprise steps of thinking 'moves', which may be considered while investigating the key frames or creative hinges for concept development, protocol methods can be implemented to compare various aspects in different design processes. Classical protocols rely on verbal accounts given by subjects of their own cognitive activities. It is difficult, however, to envisage what is going on in the designer's mind other than by listening to their verbalisations and observing any accompanied cognitive activities and designing actions, such as idiosyncrasies while sketching. Protocol methods are useful to distinguish the variety of thinking repertoires among the participants in design collaboration; every designer has his or her own 'repertoire of domains', 'structure of priorities', and 'web of moves*'* (Schön 1983). Types of protocols are threefold: (1) *retrospective* verbal accounts (presentational), recalling what one was thinking recently, offer a means of getting at cognitive activity; (2) *concurrent* verbal accounts (thinking aloud) – increasing the social behaviour while thinking aloud which offers the hope to the researcher to generate his/her thoughts and cognitive activities; and (3) *non-verbal* thinking – using visual material, sketching and other means of representations seems to be fundamental.

3.8 Reliability and Validity

The internal validation for the research methods and collected data is ensured by differentiating the design briefs, projects types and functional requirements that are examined in each experiment. Two different design briefs are outlined in the empirical chapters (Chapters 6 and 7), where each brief presents different conditions and settings to consider while pursuing designing: the first provides 'free rein' to the architect to design freely with no specific requirements for functional elements; the second provides certain specifications of detailed functional requirements accompanied by the imposition of an external condition to include an additional functional element midway through the design process.

Inviting architects from different backgrounds and practices, with a variety of experiences and skills of designing using different design tools and techniques, confirms the external validation. A standard level of experience is 10 years' practising architectural design in different firms in the UK and internationally.

3.9 Key Findings of Chapter 3

- Design complexity of a multivariate nature induces the adoption of mixed research methodologies and the empirical study of the nature of design processes.
- The reliability and validity of the coding scheme and data analysis is tested against a variety of design experiments and invited architects.

Chapter

4 Segmentation and Coding Scheme: *Methodological Development*

This chapter proposes a segmentation and coding scheme that aims to capture the structure of reasoning in the design process. This scheme identifies the design segments of 'moves' and 'critical actions' in order to construct a linkograph. It detects the emergence of sudden mental insights, eureka and aha events that take place in the formation of novel concepts. By reviewing predefined coding schemes, we aim to identify the advantages and disadvantages in the application of those schemes on several design processes and decide which methods are apposite while investigating the phenomena associated with creative discovery. This chapter sets the main parameters for coding and detecting the critical actions and sudden insights while looking at the nature of design processes. It introduces the parameters of investigation for the empirical study.

This chapter tests the hypotheses of predefined coding schemes in this field of research. It evaluates the resulting codes while constructing the linkographs for different pilot case studies. It inspects the definition of design 'move' and 'critical action' in Goldschmidt's method (Goldschmidt, 1990, 1992, 1994, 1995, 2014), the levels of 'cognitive activity' in the macroscopic cognitive scheme (Suwa et al., 1998a, 1998b), and the relations between functions, behaviours and structures in the function-behaviour-structure (FBS) coding scheme (Gero, 1990, Hybs and Gero, 1992; Gero and Kannengiesser, 2002). These schemes are widely deployed in this area of research and we intend to examine different components by searching the outcome of combining these schemes or by relying on each one alone to describe the emergence of creative events in two separate pilot experiments.

Our question for this chapter is: What level of segmentation can the design process be decomposed to in order to avoid minor activities and to capture the true structure of reasoning in the thinking process? The aim of this chapter is twofold: first, it tests the predefined schemes through the deductive approach of hypothesis-testing; and second, it develops a coding scheme for a sketching-based process grounded on collecting a wide sample of data through the inductive approach. It also examines the proposed scheme by describing a variety of design situations and poses some resulting questions to investigate in the empirical study of the next chapters.

4.1 Transformation of Ideas versus Drastic Change of Paradigm Shift

In order to judge the transformation of design concepts from one state to another in the design process, identify the segmentation of moves and critical actions precisely, and detect the emergence of sudden mental insights, eureka and aha events, this chapter identifies the types of transformation of ideas and the drastic changes of concept in the design process. The aim of distinguishing between both aspects is to understand the nature of creative discovery in the design process. In this chapter, we aim to define the segmentation and coding scheme to detect the venues of transformation and capture precisely the change from one situation to another.

The transformation of ideas can be distinguished as two types: one that expands the design space to explore alternative solutions based on reframing the original concept, which is set at the early phase of initiation, and a second that changes and shifts the concept to a different one. We hypothesise that the drastic change occurring in the prevailing design paradigm shifting it to a different state could be a sign of creative action taking place or a eureka moment in the design process. In order to judge the context beyond the emergence of the radical paradigm shift, we must first review the types of 'transformation' and forms of 'change' that may modify the designing situation from one state to another.

Goel (1995) said that the transformation of ideas from one state to another in the design presses may take one of two forms. The first is *vertical* transformation, where the movement is from one idea to a more detailed version of the same idea, which results in deepening the problem space. The second form is *lateral* transformation, where the movement is from one idea to a slightly different idea, which is necessary for widening the problem space for the exploration of kernel ideas. Vertical transformation is the development of the original concept, but lateral transformation is the creative shift towards new alternatives within the same solution space. Figure 4.1 illustrates types of transformation according to our interpretation of Goel (1995).

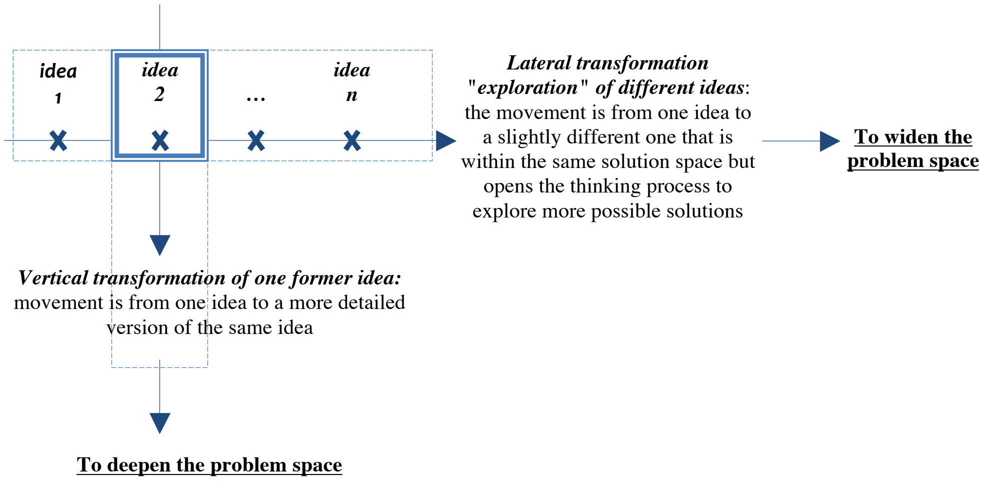


Figure 4.1 Illustration of types of transformation of idea in the design process

Rodgers et al. (2000: 461) claim that in the early stage of conceptual design, a 'good' design is characterised by the balance between lateral and vertical transformations rather than an extreme lateral bias: 'It is likely that balance will shift to an extreme (and finally total) vertical bias as the design representation progresses towards the embodiment and detailing stages'.

Craig and Zimring (2002) clarified that 'change' may take one of three forms: (1) *hierarchical* change, which takes place to accommodate the expansion of the issues that frame a search process, considered fruitful only when the emergent issues are literally separable; (2) *lateral* change, which becomes critical when the hierarchical change leads to a newly addressed problem space preventing the designer from reaching the pre-set goal – this is experienced when all the related actions are suddenly blocked; and (3) *transformative* change, when the transformation underlies the same principles of concept. The identification of the types of transformation and change in design research has been investigated in different studies that have deployed protocol methods to describe and analyse the events taking place in the design process. Before embarking on a proposition to develop a segmentation and coding scheme, we look at those predefined methods and hypotheses that aim particularly to describe creative discovery in the design process. We intend to identify the principles they stem from and the goals they aim at before we set any parameters for coding in the empirical study. Strengths and weaknesses are evaluated to assure the objectivity, reliability and validation of the coding scheme.

4.2 Predefined Protocols

4.2.1 Linkography

Goldschmidt introduced *linkography* in 1990 to represent the structure of reasoning and creative events taking place in the design process. The linkograph is constructed by parsing the recorded protocol of the design process into segments of *moves*, demarcating the moves on the baseline according to the chronological order of the time of emergence, and discerning the relationships between the related moves to form links. The meaning of 'move' in designing is akin to its meaning in chess: 'a design move is a step, an act, or an operation that transforms the design situation relative to the state in which it was prior to that move' (Goldschmidt, 1996: 72). She argues that the generation of ideas (and their inspection and adjustment) evolves over many small design moves. These combine in a network of moves, and the patterns of links in the networks manifest a 'good fit', or congruence, between the ideas. Types of transformation of ideas and forms of change along the process introduce a taxonomy of creative qualities for the actions and moves, which can be judged in the context of relations to the preceding and subsequent events.

Goldschmidt has identified two types of links that connect moves: *backlinks* are links of moves that connect to previous moves, and *forelinks* are links of moves that connect to subsequent moves. ‘Backlinks record the path that led to a move’s generation, while forelinks bear evidence to its contribution to the production of further moves’ (Goldschmidt, 1995). Thus, linkography can be considered a graphical representation that traces the associations of every move occurring. The design process can then be looked at in terms of the networks that display the structure of design reasoning. Identifying the *dependency* relations between moves is the key to constructing the linkograph, while unfolding the structure of links is the key to revealing the clustering of interaction between ideas. By understanding of the structure of linkograph, one can detect the critical events of transformation and the major paradigm shifts occurring in the design process. Figure 4.2 illustrates a hypothetical linkograph.

Linkography has been widely deployed in design research to interpret several aspects of the design process through either qualitative or quantitative means. Particular milestones of development are: identifying the ‘critical’ actions and design ‘productivity’ through *link index* (Goldschmidt, 1990, 1992, 1995, 2014); detecting the ‘creative’ actions and ‘richness’ of links through *entropy* (Kan and Gero, 2005a, 2005b, 2005c, 2008, 2009a, 2009b, 2009c; Kan et al., 2007; Gero et al., 2011); describing the ‘behaviour’ of designers as ‘operations’ on the design problem (Dorst, 2003); describing the ‘conceptual dependency’ of links and chunks (Suwa and Tversky, 1997); categorising the segments and actions of design according to a macroscopic cognitive scheme (Suwa et al., 1998a, 1998b); exploring the effect of inspiration sources on the design process through *extended linkography* (Cai et al., 2010); refining the FBS ontology for coding system (Gero, 1990; Rosenman and Gero, 1998; Gero and Kannengiesser, 2002; Kan and Gero, 2009a, 2009b, 2009c); investigating patterns of ‘problem framing’ in different design settings (Kvan and Gao, 2006); investigating ‘order’, ‘structure’ and ‘disorder’ in multilevel complex design processes (El-Khouly and Penn, 2012a, 2012b); and identifying the role of the emergence sudden mental insights in the structure of reasoning through *directed linkography* (El-Khouly and Penn, 2013).

The examination of those schemes in different pilot experiments aims to reveal the advantages and disadvantages of segmentation and coding. The following interpretations, aimed at understanding creative discovery and associated phenomena in the design process, are particularly examined: the association between ‘productivity’ and ‘creative design’ and the identification of ‘critical actions’ through the *link index* method (Goldschmidt, 1990, 1992, 1995, 2014); the detection of ‘creative’ ideas through the ‘richness of links’ and proposition of *information entropy* measure (Kan and Gero, 2005a, 2005b, 2005c, 2008, 2009a, 2009b, 2009c; Kan et al., 2007; Gero et al., 2011); and the categorisation of design actions according to the ‘macroscopic cognitive scheme’ (Suwa et al., 1998a, 1998b).

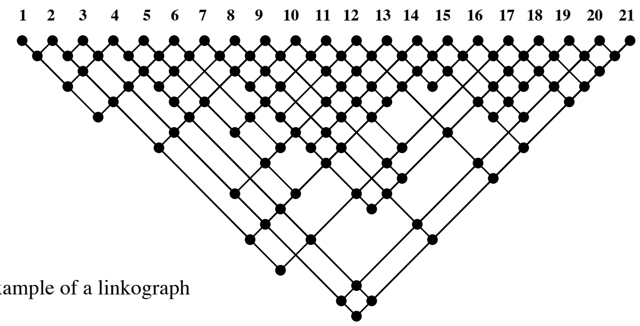


Figure 4.2 A hypothetical example of a linkograph

- **Hypothesis A: Productivity versus Creativity**

Goldschmidt (1992) suggested that the linkograph pattern of a productive designer looks different from that of a less productive designer, assuming that productive designers will make moves that have a high potential for connectivity to other moves, while less productive designers will have more random trails with moves without much potential for contribution to the design concept.

Goldschmidt explained what parts of the design process can be observed and measured in a linkograph, describing its features and notation conventions. In her opinion, the most significant elements in a linkograph are the *critical moves*, which are *particularly rich in links*. In this way, critical moves point at those actions that are highly connected to other events in the design process. Goldschmidt hypothesised that design *productivity* is positively related to the link index and critical moves; higher values of link index and critical moves indicate a more productive design process (Goldschmidt, 1990, 1992, 1995, 2014; Goldschmidt and Tatsa, 2005). Link index (LI) is the ratio between the ‘number of links' and the 'total number of moves' in the linkographs, where a critical move (CM) is rich in the total amount of backlinks and forelinks. The *critical path* is the sequence of critical moves, which can be used to compare different design process quantitatively. High link index value indicates more ideas are generated, known as: *value significance*.

In this exposition, this link index and critical moves approach is biased towards a highly linked linkograph; the 'total number of moves' indicates a 'saturation' state where all possible links are interconnected. But Kan and Gero (2005a) argue that this interpretation lacks objectivity: while a saturated linkograph will have a high value of link index and critical moves, all moves will then be interconnected showing a total integrated design process with no diversification between moves, indicating that premature crystallisation of one idea may have occurred. A fully saturated linkograph indicates less opportunity for quality outcomes of design products (Kan and Gero, 2005a).

The behaviour of links in linkography has been investigated in two different studies. Van der Lugt (2003) classified links into three categories according to the alteration of link direction. In this study, *design idea generation process* was investigated by tracking the alteration of 'link direction' in each linkograph. The correlation between the *creative qualities* of ideas and *well-integratedness* has been considered by looking at the categories of links. Van der Lugt concluded that the linkograph of a 'well-integrated', 'creative' design process is formed from three types of networks: large networks of links, low level of self-links, and balance of links of *supplementary modifications* and *tangential* links; this is known as the *hierarchical typology* of links.

According to Van der Lugt's categorisation of links and networks, Dorst (2004) investigated the *linking behaviour* regarding two particular points – *design problem* and *solutions* – aiming to reveal the reflective practice of designers. In this study, it was observed that the patterns of linkograph for high productive processes are different from low productivity behaviour. While the highly productive process comprises moves with high potential connectivity (i.e. the architect explores different options then selects one to develop the concept), low productive behaviour comprises random trails of moves with less potential contribution to the design concept (i.e. the architect uses a holistic approach without exploring different options or proposals).

Although it may seem that there is a consensus that 'high productivity of ideas' is an indication of 'quality' in the design process between Goldschmidt (1992, 1995), Van der Lugt (2003) and Dorst (2004), Goldschmidt (2014) pointed out the importance of reasserting this hypothesis and avoiding misinterpretation by correlating the link index value with additional analysis that specialises in inspecting design quality to ensure the validation of results.

> A link index is a fast indication of the amount of linking activity in a design episode, which in turn hints at the designer's effort to achieve a synthesis. However, we must be careful not to conclude that a high L.I. is necessarily a hallmark of good or creative design. A high L.I. may be the result of many repetitions or many attempts to explore alternative ideas with little continuity among them. Indeed, we found no correlation between L.I. values and design quality (Goldschmidt and Tatsa 2005). The link index is thus a value that must be used cautiously and only where appropriate (Goldschmidt, 2014: 70).

As such, the association between 'creativity' and 'productivity', 'quality' and 'richness of links' (i.e. link index), is still a matter of investigation in the empirical studies of this dissertation.

- **Hypothesis B: Entropy versus Creativity**

Gero and associates (Kan and Gero, 2005a, 2005b, 2005c, 2008, 2009a; 2009b; 2009c; Kan et al., 2007; Gero et al., 2011) proposed to use Shannon's *entropy of information* (Shannon, 1948; Shannon and Weaver, 1949), instead of the link index to acquire information from linkographs. They intended to measure the 'rate of information' carried by a message or symbol, which is based on the probability of its outcomes. They hypothesised that if there is only one possible outcome while designing, there is no additional information because the outcome is known. Information can then be defined related to the 'surprise' it produces or the decrease in uncertainty (Kan and Gero, 2005c: 234). 'Given that event "X" has a lower probability than event "Y", I should be more surprised if X had occurred, hence I get more information' (Kan and Gero, 2005a: 454).

Kan and Gero were able to distinguish between various types of cognitive patterns that are primarily involved in the design thinking process through their investigation of types of linkography patterns; either fully integrated, structured, saw-tooth (mechanistic) or sparse (2005a: 453). In their opinion, the design process is a combination of different cognitive patterns, which can be expressed in the form of a structured linkograph with partial links: ‘a partially linked linkograph embodies a balanced process that embraces integration and diversification of ideas’ (Kan et al., 2007: 369).

Finke et al. (1992) considered that creativity is not a single unitary process but a product of many types of mental processes collectively setting the stage for creative insight and discovery. In Kan and Gero’s exposition, *idea generation* and *creativity* share some common characteristics: while design moves are considered to be the externalisation of the mental processes, the collective moves can be seen as the clustering of ideas. Accordingly, by proposing the use of entropy as an objective measure of the idea generation processes, Kan and Gero hypothesise that evaluating ‘surprise’ and ‘uncertainty’ for each cluster of ideas may demonstrate creativity in the design idea generation process of the entire session. Thus, venues of creativity can be identified for the other clusters along the design process to its end. The hypothesis is that ‘high entropy reflects a rich idea generation process’, while the assumption of ‘rich idea generation process’ means that ‘the structure of ideas is reasonably integrated and articulated, and comprises a variety of moves’. *Shannon’s entropy* was therefore introduced to acquire quantitative information from the linkograph.

Kan et al. (2007: 369) outlined the following principles to show how their hypothesis led to using Shannon’s conception of entropy. While a partially linked linkograph embodies a balanced process that embraces integration and diversification of ideas, a fully linked or empty linked linkograph is highly compressible in terms of communicating it. One type of signal is sufficient to describe it: either ‘ON’ or ‘OFF’. If there is only one possible outcome (i.e. fully linked or fully empty linkograph), then there is no additional information because the outcome is known. A partially, random linked linkograph is highly incompressible, which means that much more information is needed to communicate it. In this case, the relations of links vary between two possible symbols: ‘ON’ and ‘OFF’. Thus, Shannon’s entropy takes the following equation:

$$\mathbf{H = -\sum_{i=1}^{n_{max}} \mathit{P}i \log_b \mathit{P}i} \qquad \dots \dots \dots \text{(I)}$$

Where n_{max} is the maximum value and P_i is the probability of (ON and OFF), b is the base of the logarithm that in this case equals 2 (the number of possible probabilities)

$$\mathbf{H = -\,(\mathit{p}_{ON}.\log_2 \mathit{p}_{ON}) + (\mathit{p}_{OFF}.\log_2 \mathit{p}_{OFF})} \qquad \dots \dots \dots \text{(II)}$$

With a particular interest in the configuration of links and linkography patterns, Kan and Gero (2008) processed linkography via a SPSS two-step cluster algorithm. The 2nd degree polynomial fit and quadratic fit statistical graphs are applied. The standard deviation (σ) indicates ‘closeness’ versus ‘dispersion’ of clusters around the mean point, where a high (σ) value suggests that greater combination and synthesis occur between earlier and later moves. Kan and Gero concluded, ‘the links not only provide a structural view of the processes but also locate the dominant codes and the frequency of each design transformation process’ (Kan and Gero, 2009b: 228).

In another study, Gero et al. (2011) clarified that entropy varies across the time line and that the frequency of idea generation can be triggered. They explored the change of entropy over a design session to see if entropy decreases towards the end of a session for different design processes. Values fluctuate over the linkograph in response to the variation of links in each design session, i.e. the total number of relations differs from one design move to another. In their opinion, this method is justified to compare between different clusters of links for the idea generation along the design process by adopting information theory (Shannon, 1948; Shannon and Weaver, 1949).

Pourmohamadi and Gero (2011) developed an online software system called LINKOgrapher© (LINKODER© in the recent release, 2012) that constructs linkography based on the FBS ontology and computes dynamic entropy for each design session. Two ways are identified for monitoring the changes of entropy: one uses a ‘fixed time frame’ as a reference window, and the other uses a ‘fixed number of segments’ as the width of window. A fixed time frame may comprise a different number of moves when two different design sessions are compared. Entropy values must be relativised to the total number of moves in each design session (time frame) in order to precisely characterise their differences. However, this point of *relativisation*, if required to correlate entropy values for different windows across the linkograph, has not been identified in Pourmohamadi and Gero (2011). Hence, it is easier to use a fixed number of segments as reference as the procedure can be readily automated.

These methods associate the 'richness of connected events' with the 'occurrence of creative insights' in the design process. Computing dynamic entropy values across the linkograph indicate the events with high uncertainty: high entropy value. The hypothesis is high uncertainty motivates the designer to explore the design space for more solutions, thus to become more creative (Kan and Gero, 2009a, 2009b, 2013). Accordingly, the association between 'creativity' and 'richness of links', 'surprise' and 'entropy' is still a matter of investigation in the empirical studies of this dissertation. The paradox occurs if the creative insight emerges independently; weakly connected from the preceding clusters of ideas. Hence, the association between 'creativity', 'productivity' and 'richness of links'; the detection of 'creative insights' via 'entropy' is denied and requires further revision.

4.2.2 Segmentation and Coding

The main objective of segmentation is to parse the design process into its basic structural units (i.e. design moves and cognitive actions) in order to infer the structure of reasoning and the idea generation and development. Coding relations between design moves helps to understand the transformation process. The coding process must provide an objective tool to look at the design process and thinking process, but also identify the critical moves and emergence of creative insights accurately. The segments are investigated in light of the external representations of design products to observe the transformation of ideas from one state to another. This may seem at first simple to solve; however, we have faced difficulty while testing codes for the pilot cases to capture the cognitive activity of the designer. Hence, the segmentation and coding processes may include some details that would better be avoided in order to represent the design reasoning precisely.

Coding schemes can be classified into *custom* or *predefined* (predesigned) models. Custom coding schemes require intensive labour to check the objectivity and reliability of results. Predefined coding models anticipate certain stages or parameters the design thinking process must include. In most publications the segmentation and coding design processes are not explicitly defined. However, two models are widely used in this field: the FBS model (Gero, 1990) and the macroscopic cognitive scheme (Suwa et al., 1998a; 1998b). In this chapter, two questions are raised. First, the level of segmentation the design process shall be parsed to (to represent the meaningful structure of reasoning and idea generation process and ignoring unmeaningful or trivial actions). Second, the reliability of implementing a predefined coding model to identify the relations between moves in architectural design process and to introduce reduction to the segmentation process. One concern is that by segmenting the design process to every single utterance occurring the linkograph system may be flattened. Flattened networks often include dense nodes of relations. Distinguishing the differences of characteristics between nodes in the flattened linkography network becomes difficult through quantitative measurements. Both points are examined while looking at the predefined models.

- **FBS Ontology**

The combination of linkography and the FBS ontology gives a view of the network of acts in designing. It is outlined to overcome difficulties stemming from the use of custom coding schemes. Gero (1990) claimed that a basic coding scheme comprises the categories: Function (F), Structure (S), Expected behaviour (Be), Behaviour derived from structure (Bs) and Documents (design description) (D), which are considered to be a generally applicable coding basis, independent of design domains. The relationship between these components thus coded represents the following design activities: formulation (inferring expected behaviours from functions and requirements), analysis, synthesis, evaluation, documentation, and three levels of reformulation (changing the space of possible designs by changing the structures, behaviours and functions). Two additional categories are Requirements (R) and Others (O): analyses decided later in the design process. Figure 4.3 illustrates the FBS model.

By comparing the percentage of ‘segments of each code’ with the percentage of ‘links generated by segments’ of the same code, we can compare the frequencies of the codes with the linking evidence. After consolidating codes into groups representing design activities, we will be able to look at frequencies of transformations. Kan and Gero (2009a) found that the most prominent type of transformation was from S to S (notated S>S), which was translated into level 1 reformulation. Next were analysis (S>Bs), evaluation (Be<>Bs), and synthesis (Be>S), in descending order of occurrence and percentage. Regarding the distributions and frequencies of codes in design processes, theses parameters include first-order and second-order Markov chains and entropy calculations.

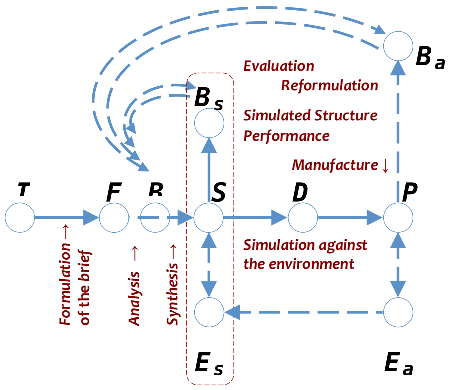


Figure 4.3 FBS Ontology
Source: Hybs and Gero, 1992.

The FBS model requires categorisation of the design moves into these predefined components. The concept stems from the technical rationality paradigm; treating the design process as cyclic, consisting of certain stages, while it discounts the epistemology of practice view to look at the aspect of ‘design situation’ for segmentation. It also abstracts the design process into a mechanism and overlooks several important factors that are often employed to develop an architectural concept, e.g. the idiosyncrasies for designing and organising the spatial configuration, the perception of visual idea (perception-in-action), unexpected discovery while reflecting-in-action, the role of mental imagery, the reliance on personal skills and talents for thinking, imagining and sketching. The use of such predefined schemes limits the applicability of the results obtained.

The changes of definitions through the development of the FBS model lack the clarity needed to code the dependency relations among the emergent actions. Neither the ‘cyclic’ nature of co-evolutionary stages nor the definitions of ‘function’, ‘behaviour’ and ‘structure’ can be generalised in every design process. This drives us to adopt a different *custom coding scheme* to describe the context where design actions stem from. The FBS model is excluded from the empirical study.[30]

- **Macroscopic Cognitive Scheme**

Suwa and Tversky’s scheme (1997) devised a general taxonomy to classify the contents of the design process where the major dichotomy was drawn between *visual information* and *non-visual information*. Visual information is divided into ‘depicted elements and their perceptual features’ and ‘spatial relations’, distinguishing between ‘what’ versus ‘where’ in visual and spatial cognition. Non-visual information is classified as ‘functional thoughts’ and ‘knowledge’. The significance of this scheme is that it provides the basis for examining inherent dependencies between pieces of information belonging to different categories. It takes into account the idiosyncrasies that are involved in the design cognitive process while coding the dependency relations between moves.

[30] Dorst and Vermaas (2005) analysed the FBS model and showed that at least two different versions of the model can be distinguished, Gero (1990) and Rosenman and Gero (1998), which raised fundamental questions about the precise location of the transition between *structural* and *intentional* descriptions of artefacts and the empirical status of the model as a whole. The definitions of function, behaviour and structure have different implications with at least two different versions of the FBS model (Dorst and Vermaas, 2005: 25). Gero and Kannengiesser (2002) gave rise to a version of the FBS model that seems similar to the original version of 1990. For example, in Gero and Kannengiesser (2002) the differences between these versions were illustrated by locating the transition of the intentional description of artefacts to the structural description of those artefacts in the versions. However, in Gero (1990), this transition is divided over both the formulation step F→Be from function to expected behaviour and the synthesis step Be→S from expected behaviour to structure. In Rosenman and Gero (1998), it is located either in the formulation step P→Fe from purpose to expected function, or divided over this step P→Fe and a second formulation step Fe→Be from expected functions to expected behaviour. In Gero and Kannengiesser (2002) the difference between these versions seems located in the steps that transform expected functions (Fe) to expected behaviour (Be). FBS ontology for coding relations between design moves is explained in Appendix 2.1.

For example, the architect's attention to a spatial relation between two regions in a sketch is based on the inspection of the physical depiction of each region, which belongs to 'depicted elements and their perceptual features'. When an architect thinks about 'people's circulation' from one region to another, which belongs to 'functional thoughts', it occurs in his/her mind suggested by the appearance of a spatial relation between the two regions in the sketch. Suwa and Tversky suggested that dependencies of this sort between cognitive actions belonging to different categories are the key to understanding the ways in which designers cognitively interact with their own sketches.

Following Suwa and Tversky's principles (1997), Suwa et al. (1998a, 1998b) advanced the macroscopic cognitive scheme with a particular aim of defining actions of design systematically. Activities are represented as a structure composed of defined basic actions. It helps to understand how designers cognitively interact with the interim sketches to achieve the session goals. It classifies the emergent actions (moves) into four categories; *physical*, *perceptual*, *functional* and *conceptual*, to understand the transition between these cognitive levels in the design process. The scheme was built according to the following sources of information:

First, the categorisation of visual and non-visual information (Suwa and Tversky, 1997). Second, the levels of information processing in human cognition. Third, past literature on what professional assessors of design environments have discovered about what designers *attend to* or *think of* while designing, which became a reference in obtaining the major categorisation of the scheme. Accordingly, Suwa et al. conjectured the criteria for classifying the four cognitive categories into other subcategories to identify *action categories* for each type of cognitive level (see Table 4.1). Fourth, ethnographic intensive observations of 'video/audio' protocols for architects while practising. The validation of this scheme was achieved through a repeated process of establishing a set of categories theoretically, testing the criteria on several examples and developing the coding scheme until its final form was established.

Table 4.1 Action categories in the *Macroscopic Cognitive Scheme*

Category	*Subcategory*	*Description*	*Examples*
Physical	*D-action*	Make depictions	Drawing lines, circles, words
	L-action	Look at previous depictions	—
	M-action	Other physical actions	Moving elements, gestures
Perceptual	*P-action*	Attend to visual features of elements	Shapes, sizes, textures
		Attend to spatial relations among elements	Proximity, alignment, intersection
		Organize or compare elements	Grouping, similarity, contrast
Functional	*F-action*	Explore the issues of interactions between artefacts and people/nature	Functions, circulation of people, views, lighting conditions
		Consider psychological reactions of people	Fascination, motivation, cheerfulness
Conceptual	*E-action*	Make preferential and aesthetic evaluations	Like–dislike, good–bad, beautiful–ugly
	G-action	Set up goals	—
	K-action	Retrieve knowledge	—

Source: Suwa et al., 1998a.

Segmentation divides the design process into small 'moves', which are categorised and coded according to the set of action categories; cognitive actions are coded corresponding to the four levels at which incoming information is thought to be processed in human cognition. The levels of information processing have an inherent dependency on each other; processing at an upper level is based on that at lower levels. A design action coded into an upper level should be inherently dependent on other actions coded into lower levels.

Indices of whether or not actions in a segment are new in the process are decided by coding an 'index' for each action. There are three types of indices; *new*, *continual* or *revisited*. For example, if a designer thinks or takes action for the first time the index will be 'new'; if, at a segment, he/she continues a design action from the immediately previous segment, then the index is 'continual'; and if the designer returns to a design action done at an earlier, but not contiguous, segment, then the index is 'revisited'. Some actions are 'dependent on' or 'triggered by' other actions of the same or lower levels. This point is similar to the concept of tracking design moves by using 'forelinks' and 'backlinks' in the linkography analysis.

This method is advantageous for defining the basic units in the design process including the cognitive actions and design moves in a systematic way. Suwa et al. (1998a; 1998b) debated that the identification of the designer's cognitive behaviour is based on well-structured, well-defined basic actions in each of the local design stages, which in turn brings our query on the nature of research paradigm to the surface:

What is the role of the research paradigm (i.e. technical rationality vs. epistemology of practice), which the model stems from, *in directing the researcher's attention to identify specific factors while analysing the design process and disregarding any confounding factors that may have an effect?*

4.3 Adjustment of Segmentation and Coding Schemes

In this section, we aim to adjust the segmentation and coding scheme to detect the design moves and critical actions precisely in order to capture the structure of reasoning, transformation of ideas and drastic changes of concepts. It is necessary to adjust the measurements of segmentation before testing the proposed hypotheses: Hypothesis A *creativity is associated with productivity* (Goldschmidt, 1990, 1992, 1995, 2014), or Hypothesis B *creativity is associated with the richness of links, connectivity or information entropy* (Kan and Gero, 2005a, 2005b, 2005c, 2008, 2009a, 2009b, 2009c; Kan et al., 2007; Gero et al., 2011). This takes place through the empirical study; our aim is not to test the empirical data against the predefined models and associated hypotheses but to identify the disadvantages in these schemes and develop our coding method accordingly.

Before embarking on the primary design experiments to deduce the nature of design processes and creative discovery, the predefined schemes are tested in the following pilot experiments. The epistemology for this adjustment is twofold: a deductive approach testing the predefined coding schemes against pilot experiments and evaluating the results to decide the advantages and disadvantages of predefined methods; and an inductive approach collecting data for different design situations, testing and developing a situated segmentation and coding scheme.

4.3.1 Pilot Case Study 1: Remote Collaborative Design Process

This study aims to examine the effect of an online remotely located design setting and communicating medium on reducing the bandwidth between designers in a collaborative design process to generate ideas and sketches and form spatial concepts for the competition of the new premises of the faculty of architecture, University of Delft, Netherlands. The competition was organised by TU Delft in 2008 for registered architectural students in worldwide universities and young visionary architects to design proposals to rebuild the faculty of architecture after a devastating fire with the theme 'Building for Bouwkunde' (building for architecture). Later, this competition was taken to an advanced level calling on international architectural firms and designers for entries in 2009.[31] Figures 4.4 illustrates snapshots of the desktop-sharing platform and figure 4.5 presents the final product of the competition entry.

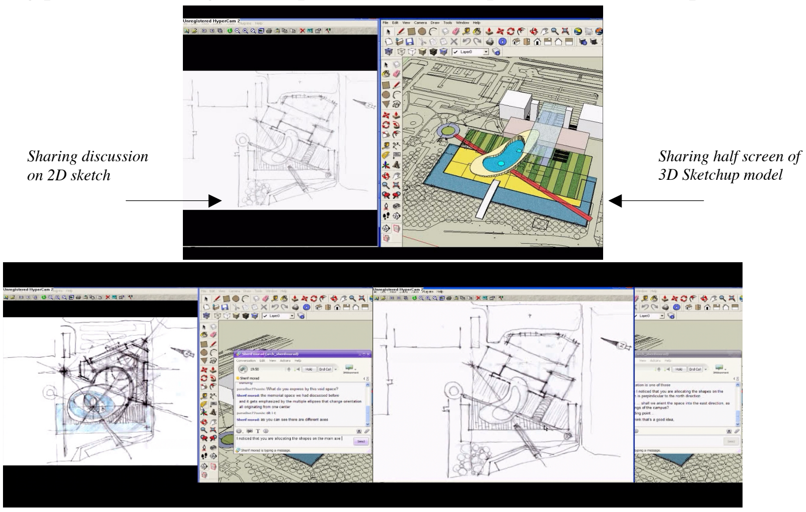


Figure 4.4 Snapshots of the desktop-sharing design platform

[31] This pilot study is described in detail in Appendix 4.2

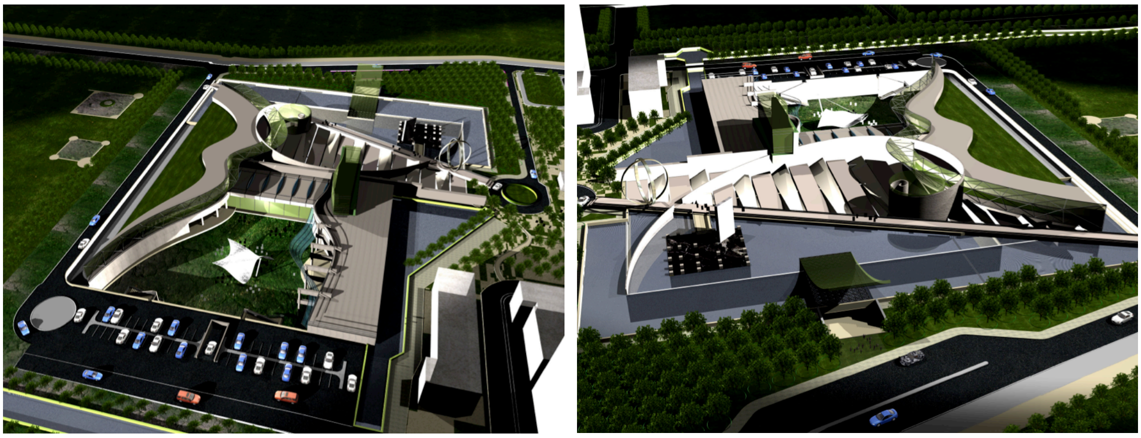


Figure 4.5 Final product of design collaboration – TU Delft competition entry (2008)
Source: Tamer El-Khouly and Sherif Abdelmohsen

- ***Linkography***

Action categories, dependency and triggering relations are deployed to construct the linkograph of this partial design session (see Figure 4.6). This linkograph shows weakness in the structure of relations at the venues 21–27 and 45–52, where a fixation effect was experienced undermining the generation of ideas and solutions for the problem under investigation. It draws links only for the dialogue between designers. It does not show a variety of pattern and is sparse with a low level of relations.

However, this basic linkograph disregards an important factor, which is to draw links between the actions that represent discussions of similar concept ideas of spatial forms and functions among the interim products, which is completed in Figure 4.7, showing those relations in colours dependent on each design medium. By this overlap in the layers of patterns in the linkograph, we aim to detect the role of the multiple switches of design media to compare ideas or exchange information between the interim artefacts in the structure of reasoning and idea generation. The benefit of this method (overlaying different layers in linkography, joining linkography with the cognitive scheme) is twofold. First, it helps to judge the venues of transformation of ideas or drastic change occurring in the state of design in relation to those interim products. Second, it reveals the transition between the four cognitive levels and sub-categories while designing, particularly at the generation of good ideas. Accordingly, the occurrence of critical actions in the design process can be accurately identified via this method. This is supported by overlaying the analysis with the designers' verbal protocols, retrospective comments and ethnographic observations of the design process.

- ***Identification of 'Critical Moves'***

Examining the linkograph in two different modes – one including design actions and verbalisations, and another including the relations of 'media switching', which illustrated the exchange of information between different design products to develop the concept (i.e. comparing the conceptual idea between the present and preceding situations via different sketches) – helped to identify the role of mutual exchange of information (back/forelinking) via design media sketches in the occurrence of critical actions, evolving solutions and the unexpected discovery of solutions through the design process.

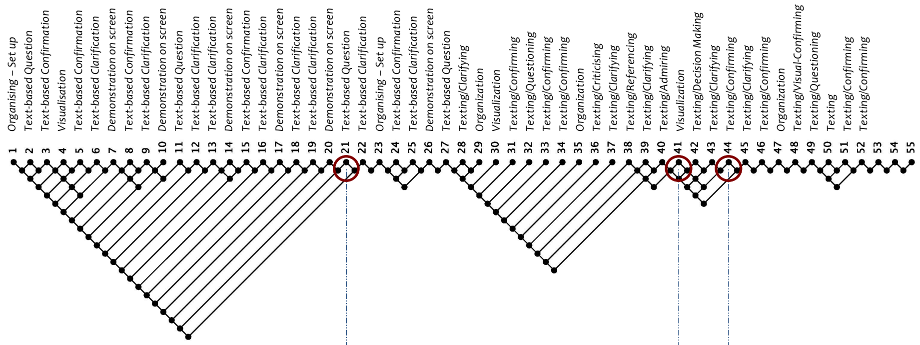


Figure 4.6 Linkography for the dialogue between the collaborators

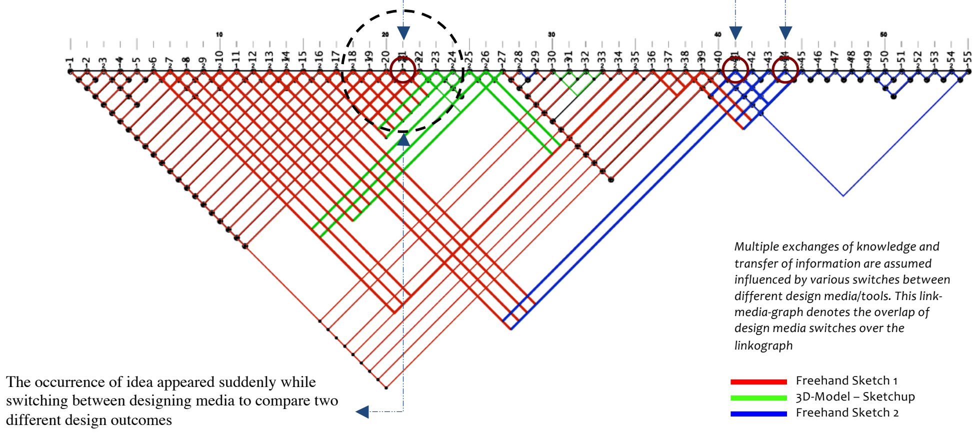


Figure 4.7 Linkography: linking the relations of similar conceptual ideas between different designing media

- ***Link Index***

The *link index* is a statistical description for the critical moves. It was introduced by Goldschmidt (1990) as the ratio between the 'number of links' and the 'total number of moves'. Goldschmidt stated that a high value of link index is an indication that good ideas are generated in the process. In Pilot Case Study 1, the link index for critical moves is estimated as shown in Table 4.2.

According to the link index values for actions '21', '42' and '45', the values are very low, which refutes Goldschmidt's hypothesis. Design quality for these actions has been identified through the description of the design context and emergent ideas. The link index indicates the highly integrated patterns in the linkograph. In this case, the 'richness of links' in the linkograph is not enough to indicate the 'quality of generation of distinctive ideas' or to identify the 'critical moves'. We debate that a high link index value is an indication that the design moves are interlinked, which is a positive sign for a structured pattern. This is stated as reflecting coherence of reasoning and homogeneity between moves (Kan and Gero, 2005a, 2005b, 2005c; El-Khouly and Penn, 2012a). However, the more the design actions are interlinked, the attachment of certain concepts increases, which could cause fixation to diffuse in the process. In a fully connected linkograph, the saturation state where all moves are interlinked gives the maximum value of link index, refuting the assumption that the link index indicates creativity of design.

Table 4.2 Link index [LI] value per each critical move and the percentage over the total number of moves

Total Number of links = 114 Total Number of moves = 56 Link Index LI = 114/56 = 2.036	LI of CM (#21) = (11/56)*100 = 19.64% LI of CM (#42) = (9/56)*100 = 16.07% LI of CM (#45) = (6/56)*100 = 10.71%		
	CM (Move #21)	**CM (Move #42)**	**CM (Move #45)**
Forelinks	4	3	3
Backlinks	7	6	3
Total	11	9	6
Link Index	(11/56) = 0.196	(9/56) = 0.161	(6/56) = 0.107
%	**19.64%**	**16.07%**	**10.71%**

- ***Creative Events versus Shannon's Information Entropy***

To decide which design moves were critical, each emergent product has to be compared to with other interim product as well as the final one at each action throughout the design process, capturing the significant ones. This method concludes that actions 21, 42, and 45 are critical in this development. In this study, Kan and Gero's method of Shannon's entropy is deployed to quantify the linkograph and to re-examine the method to see if the chunks of links where these critical actions emerged can be detected (Hypothesis B). Relations between moves have been coded and LINKODER© application used to estimate entropy for those venues of chunks of links; once for 6 segments window-size, next for 14 segments window-size, and lastly for 28 segments window-size. Our goal of deploying Kan and Gero's application of entropy is to test the hypothesis of whether 'richness of links' is directly related to 'creativity'. Figure 4.8 illustrates the overlaid entropy measurements on the linkograph for the pilot case study 1. According to this estimation we find that:

- For move '21', dynamic entropy is relatively high for the chunk where the action emerged for a window of 6 segments, but delivers low values for windows of 14 and 28 segments.
- For move '42', dynamic entropy is low for the chunk where the action emerged for a window of 6 segments. However, the application disregarded the estimation for windows of 14 and 28 segments. This is because the network is flattened, has few relations and thus low probability that is almost negligible in LINKODER© estimation process.
- For move '45', dynamic entropy is relatively high for the chunk where the action emerged for a window of 6 segments, but delivers low values for windows of 14 segments. However, the application disregarded the estimation for windows of 28 segments, due to a flattened network state.

We conclude that for the application of Shannon's entropy on groups of nodes (chunks of links) in the linkograph, the results of dynamic entropy differ for the same chunk according to the window-size, which may deliver high or low values. According to the fluctuation of results between high and low variations for the same critical action, we conclude that:

1. Shannon's entropy of LINKODER© application is a sensitive measure when dealing with small-sized systems such as linkography. It gives negligible results for small-sized chunks despite the existence of links of relations between nodes in the network (i.e. the chunk from actions '30' to '35' delivers zero entropy value for window of six segments).
2. A small network (window of 6 segments) does not reflect the real state of concept development particularly in the case where the architect creates synthesis of long back/forelinking (i.e. between an old idea and the present situation). Thus, it is suggested to enlarge the window size for the estimation of backlink entropy to capture the structure of reasoning of long back/fore linking and detect the effective relations between the emergent design move and the earlier events, which may contribute in the concept development.
3. Accordingly, we may hypothesise instead that 'the larger the window' (includes many segments), 'the higher the accuracy of dynamic entropy values', which reflect the reality of concept development and transformation. However, in Pilot Case Study 1, the estimation of entropy values for relatively wide window-size of 14 and 28 segments show very low or negligible values respectively, which may draw a concern that LINKODER© is not capable of detecting the real structure state for the chunks of segments in the design process through Shannon's entropy. Knowing that the linkograph of this pilot study is sparse, the density of relations in the network may be considered an effective factor in the estimation process.
4. Relativisation is a crucial factor in adjusting the values, especially if the tendency is to compare the values between different networks. Values can be relativised to the logarithm (base 2) for the window size for each case.
5. Finally, we conclude that for Pilot Case Study 1, LINKODER© could not capture the emergence of good ideas. It acquires information for the structure of relations quantitatively but the quality of the emergent ideas and their role in the concept development and structure of reasoning is disregarded in this method.

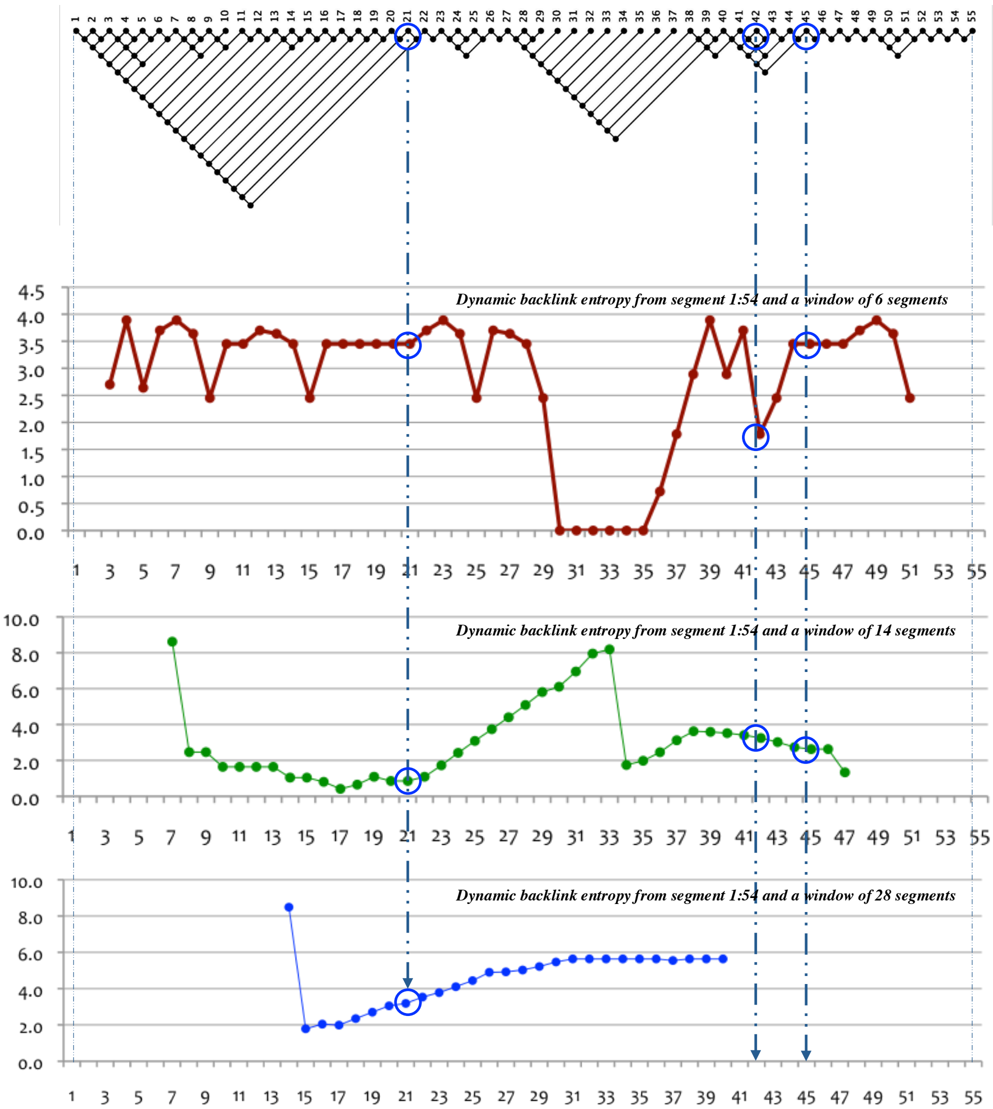


Figure 4.8 Dynamic ‘backlink entropy’
Source: Author’s computation of Shannon’s entropy using LINKODER application.

- ***Results and Discussion***

The integration of ‘linkography’ and ‘cognitive scheme’ in one analytical framework helped to describe the events that took place in the design process from two different perspectives. On one hand, linkography provided a thorough approach to deduce the structure of relations in design reasoning, and on the other, the cognitive scheme distinguished the characteristics of cognitive actions in relation to the emergent products (ideas and moves) through the interplay with design media (artefacts) in the collaboration process. Thus, in order to understand the context beyond the creative ideas evolving, this proposition identified the role of ‘reflective practice’, ‘knowledge transfer’ between ideas of design artefacts (media), and the ability to generate ‘critical solutions’ through comparisons. In this sense, design quality can be addressed by understanding the role a critical move (solution) may play in design reasoning and transformation of ideas.

We suggest that to interpret the creative quality of a critical move is to identify the relation of its emergent concept (content) to the formation of a final product. Thus, to assess its effective role in the reasoning process is to determine the quality of an emergent idea on the design process (as a whole context). However, to conduct a pairwise comparison between every two sequential products occurring is to detect the effect of the evolving actions (critical moves) either in the transformation of idea or the entire change of product (as a local context). Thus, the ‘critical path’ of concept development can be judged. To draw a datum-line (DL) for the evolving critical actions through the design process is to determine the trajectory of concept development with its pivotal venues and key actions of creativity. Through this datum-line, the evolution of ideas and collective reflection-in-action can be identified between the designers in team collaboration.

This proposition helped to reveal the role of leadership in the reflective practice, especially when that fixation effect disseminated across the thinking process and undermined the generation of ideas to solve the problem of 'orientation for the master layout'. Overlaying the linkograph with a layer for the relations of *'media switching',* which illustrated the exchange of information between different design products to develop the concept, helped to reveal the evolving solution. One designer managed to retrieve a different sort of knowledge by returning to an earlier conceptual sketch to compare the concepts and generate the solution.[32]

In Pilot Case Study 1, we aimed at answering *how the role of emergent design moves (decisions-making, idea generation of the interim artefacts) in concept development (transformation or change) can be captured.* In doing so, the design process was segmented into structural units, the dependency and triggering relations were coded, and types of activity and interactions for each designer were identified and represented to extract their contribution in concept development from two different perspectives. The model revealed a remarkable commensurate relation between design reasoning and the interplay with the products for the displacement of concepts and exchanges of frames of reference.

- ***In Conclusion***

We started by conducting a self-participatory, remotely located, collaborative design case study, which shed light on the aspect of 'reflective practice' between both designers, highlighted the contribution of each on 'problem formulation' and 'solution generation', and unveiled the role of the manipulation and interplay with the design artefacts. This design experiment provided useful insights on how design concepts can be initiated under special conditions of remote collaboration, online desktop-sharing medium, synchronous and asynchronous designing, expertise and exchange of leadership positions (leader–follower position while using one pencil/cursor), and the role of reflective practice. The segmentation and coding scheme categorised the cognitive actions to certain macroscopic levels and distinguished the contribution of each participant during the critical events, to overcome the fixation and generate the solution. The distribution of expertise between us helped to diversify the sources for creative concepts and quality of ideas, as Dunbar (1995) elaborated.

In conclusion, we infer that the more the designer(s) exchange information between different media (switching on/off between the sketches), making comparisons between different concepts, the more it becomes possible to structure the thinking process and synthesise the concept through homogeneous transformation between ideas from a state to another. Building a back-and-forth linking process between old concepts and present situations supports the transformation and averts the experience of fixation. The ability to break out of a frame of reference and shift to a new one is a trigger for a creative insight (Akin and Akin, 1996). This is assessed through the performance and productivity throughout the process. Creative insights act as creative hinges for the generation of good ideas in the design process. The ability to create reflections on the emergent artefacts to improve the concept by articulation and avoid fixation is an important aspect for creative discovery.

In the next Pilot Case Study 2, we examine a more complex design process. We re-examine the segmentation and coding scheme in a different context by testing the structure of relations of design moves in the linkograph. The main objective of this chapter is to develop the coding scheme to capture the structure of reasoning and events that are taking place, to infer the reflective practice and interplay with the interim design artefacts on the occurrence of creative actions and idea generation. The main question remains: *What is the appropriate level of segmentation the design process is decomposed to in order to avoid minor or trivial activities and to capture the real structure of reasoning in the thinking process?*

[32] See Figure 4.7 to detect the intersection between the 'red' and 'green' lines in the linkograph that coincides at action '21'. Refer also to the index of cognitive action to detect the increase in the perceptual actions while switching between both media.

4.3.2 Pilot Case Study 2: Solo Design Process

This study investigates how the architect interacts with his/her own sketches and the mutual reflections that can be made during this hypothetical dialogue. The role of freehand sketching has been identified in several studies as helping the designer to send quality ideas from the mind to the sketch and vice versa. As described by Goldschmidt (1991) sketching plays an imperative role in the process of unexpected discovery while designing. Our question is: *How can we segment the sketching episodes into quality segments that represent the structure of reasoning*? To answer this question, a new pilot study is outlined, this time to examine the solo design process: to design a pavilion in *Expo Shanghai 2010* for the theme 'the image of your country'.

- **Design Settings:**

This new pilot experiment was set up for solo mode designing not collaboration, providing conventional tools of freehand sketching, AutoCAD, *SketchUp*® and *3D Studio Max*® applications. The brief introduced a different design task from Pilot Case Study 1, requesting an Expo Pavilion for Shanghai 2010 to represent the architect's own country. The design brief was not structured with any specifications or requirements, giving the architect free rein to design without restraint.

Design brief: Ill-defined, open-ended, provided free rein to architects to design freely and propose conceptual ideas without any specifications of a functional programme.

Design Mode: This pilot study was for individual design process. The invitee architect had more than ten years' experience of architecture practice.

Data Protocol: The verbal protocol and activities were captured by videocam, with retrospective comments by the architect on the concept development through emergent artefacts. Ethnographic observations were recorded in parallel.

- **Design Process:**

This design process lasted for one hour. A variety of sketches of conceptual artefacts and decisions resulted at the end of this design experiment, providing rich and diverse data to build the final concept on.

- ***Segmentation and Coding***

Transcription, segmentation, and coding processes were applied to each design case, and linkographs were constructed. However, a critical point was revealed about the segmentation scheme, which has decomposed the design process into minor actions that will not benefit our understanding of the reasoning process and concept development. Rather, it misleads the description of linkography to detect the critical actions and creative events taking place in the process. Table 4.3 presents part of the transcription and segmentation, which ended up by confusing the categorisation process for the emergent actions according to the cognitive types of the coding scheme.

- ***Linkography***

Constructing the linkograph has passed three sequential steps: the first network of relations includes the designing actions (physical, perceptual, functional and conceptual); a second layer of relations includes the back/forelinking between different media for similar concepts (e.g. the tracing actions, comparisons, knowledge transfer), and third is the summation of both layers. This ended up as highly dense networks of linkograph. Figure 4.9 presents the three-step process to construct the linkograph for Pilot Case Study 2.

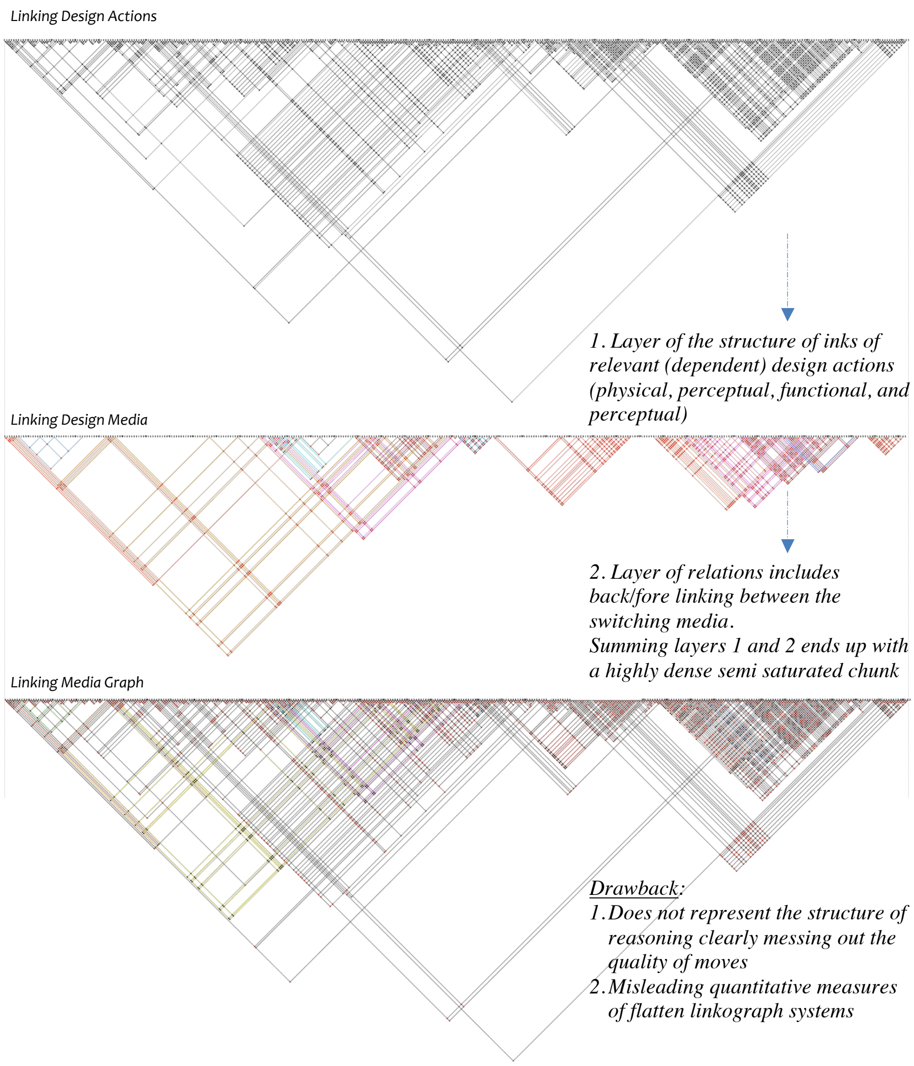


Figure 4.9 The overlap between linkography and link-media-graph leading to a flattened system

Table 4.3 Transcription of design actions into a protocol sheet – Pilot Case Study 2

#	Start Time		End Time		Parti-cipant	Medium	Activity Type	Activity Protocol	Action Category	Macro Level
1	0	0	0	0	1	design brief	Reading; retrieving information		conceptual	K-action
2	0	0	0	14	1	sketch_01_a	sketching first line		physical	D-action
3	0	14	0	16	1	design brief	switching medium			
4	0	16	0	18	1	design brief	reading		conceptual	K-action
5	0	18	0	24	1	sketch_01_a	drawing		Physical	D-action
6	0	24	0	35	1	internet	browsing		conceptual	K-action
7	0	35	0	44	2	conversation	clarification	introducing brief, You are requested to design …	conceptual	G-action
8	0	44	0	49	2	conversation	introduction	Another sketch is available to use …	conceptual	G-action
9	0	49	0	50	1	conversation	confirmation	Ok	conceptual	E-action
10	0	50	1	10	1	conversation	question	the prevailing wind …		
11	1	10	1	13	2	conversation	clarification	search for it on the internet		
12	1	13	1	14	1	conversation	confirmation	yea	conceptual	E-action
13	1	14	1	20	2	conversation	clarification	Shanghai not Greece		
14	1	20	1	21	1	conversation	confirmation	ok, right	conceptual	E-action
15	1	21	2	4	1	internet	searching		conceptual	K-action
16	2	2	2	4	2	conversation	question	what are you looking for in the internet?		
17	2	4	2	29	1	conversation	answering	some images of pavilions … ideas of circulation, lighting, etc.		
18	2	29	2	32	2	conversation	question	searching for certain examples to inspire from?		
19	2	32	2	52	1	conversation	answering	general ideas		
20	2	52	3	2	2	conversation	clarification			
21	3	2	4	34	1	internet	browsing			
22	4	34	4	38	1	design brief	reading			
…	…	…	…	…	…	…	…	…	…	…

- **Evaluation and Discussion:**

This scheme captured too many minor actions while constructing the linkograph. It was disqualified from our assessment because it fell into capturing trivial events that do not reflect the real structure of reasoning. While processing the linkograph for quantitative measures, the results showed discrepant values that do not match the reality of the relations, e.g. flattened zero values for the network that include few links of relations. We conclude that the segmentation should capture the events that represent the thinking process and reasoning structure and avoid any trivial or minor unmeaningful actions. Thus, it requires improvement and reformation before coding the dependency relations.

- ***The Drawback of Flattened or Dense Networks***

Our aim of using linkography as a graphical representation to describe the structure of reasoning in the design process is to understand the transformation of concepts and changes that occur throughout, and in particular the context beyond the evolving creative ideas. The emergence of sudden mental insights is a phenomenon associated with the creative discovery that is hypothesised as involved in the formation of novel concepts and creative discovery.

However, the adoption of a predefined segmentation and coding scheme reveals a critical point for our derivation. Identifying every single action occurring while designing a *parti* (concept configuration) comes up with too narrowed episodes and many utterances. One drawback in the decomposition of the design process into small segments of moves is the impracticality of detailing the process into tiny segments that might lose the meaning of reasoning process and disregard its complexity. On the other hand, sparse networks, with few relations, expose the problem of flattened networks, which do not provide meaningful measurements particularly when quantitative and qualitative results are correlated.

In the extreme case of fully saturated linkography, measurements are almost identical, where with too many nodes connected undesirable high density is shown. It is difficult to capture the transformation of ideas in dense networks where the fluctuation of measurements is considered low and indistinguishable over the linkograph. In this case, the role of reflective practice in the occurrence of critical moves cannot be triggered in either flattened or dense networks.

Weakly connected utterances are also problematic, showing negligible values. In this case, the drawback of segmentation erupts if the design process is fine grained into minor details. Therefore, we aim at reforming the segmentation model to provide clear evidence for coding the dependency relations based on the transformation of ideas and reflective reasoning through the sketching episodes.

- ***Introducing Reduction to the Segmentation Process***

In Goldschmidt's proposition, a reduction must be introduced to the segmentation process in order to remove any repetitions or negligible actions that would affect the final structure of the linkograph. In her opinion, moves are normally small steps, but delimiting a move in a think-aloud protocol requires profound investigation to represent the structure of design reasoning adequately. A move is defined by establishing beginnings and endings of coherent utterances: 'Wherever the recording indicates that the designer started a fresh train of thought, a new move is registered: usually such utterances start with words like "OK" or "alright"' (Goldschmidt, 1990: 73). For segmentation and coding, a reduction has to be considered and introduced to the scheme in order to describe the real structure of reasoning by following these principles:

First, in team protocol of design collaboration, each utterance by each of the designers is defined as one move, assuming it is easier to parse than individual designing.

Second, a small number of long utterances that could have been subdivided into separate moves are also treated as single moves for the sake of simplicity.

Third, within each unit of the design process, the moves are numbered chronologically, with two exceptions: very brief or meaningless utterances such as 'yeah', 'mm mm' or 'em I think if' are not numbered at all and neither notated nor included in the analysis. The second exception pertains to moves that represent a complete or partial repetition of what was just said. Describing a case study from the Delft Protocol Workshop, 1990, a reduction can be introduced thus:

> For example, in the team's unit 32, move 27 reads: 'so we would do it as a strap way OK so.' This is a secondary move that does not change the state of the design, and is numbered 27a. In the notation and analysis, secondary moves do not have an independent status and are auxiliary to the main move they follow (Goldschmidt, 1990: 73).

In Kan and Gero's opinion (2005a, 2005b, 2005c) design moves can be derived via two approaches: from verbal data using the turn-taking of conversation as an indicator of the next move (e.g. design collaboration), or by coding all non-verbal events that trigger moves (e.g. drawing, gesturing). While most of these moves occur either simultaneously or in parallel with the conversation, grouping some of those with the verbal protocol would introduce reduction. The last part of this chapter presents our proposition of a segmentation and coding scheme that captures the structure of events occurring in sketching-based design process.

4.4 A Proposition of Segmentation and Coding Scheme

According to the empirical study of pilot case studies, it is noted that the characteristic of segmentation and coding is subject to the research paradigm it stems from. The difference between the predefined schemes, which was applied in this empirical study, demonstrated either the 'technical rationality' or the influence of the 'epistemology of practice'. In our opinion, the FBS ontology (Gero, 1990) and information entropy (Kan and Gero, 2005a, 2005b, 2005c, 2008) reflected the Simonian view, while linkography (Goldschmidt 1990, 1992, 1995, 2014) and the macroscopic coding scheme (Suwa et al., 1998a, 1998b) represented the Schönian view. Lack of clarity in identifying the segments and structural units of design moves and sudden mental insights was experienced while using each of these schemes.

4.4.1 Limitations of Predefined Schemes

The shortfall in the predefined segmentation scheme is threefold:

First, it is subject to *fragmentation*, capturing tiny units/trivialities that cause flattened or dense networks in the linkograph. The remedy is to introduce reduction in the final transcription scheme and adjust the level of segmentation. Most of the predefined schemes were developed to capture the verbal protocol in the Delft workshop design experiments where each action and utterance performed by the designer in the collaboration team was counted as a move. However, it was difficult to represent the structure of reasoning in the individual (solo) design process (Goldschmidt, 1990). This has encouraged researchers in other design cases to ask the designer to verbalise their thoughts while designing to build the segmentation on.

Second, it involves *subjective interpretation*. Reaching acceptable values of inter-coder reliability is difficult to achieve, particularly if there are long verbalisations by the designer to explain his/her work, which may pertain to several topics at once and thus suffer incoherency. Coders may rely on their own interpretations, which are sometimes quite speculative. This may cause differences among codes, and even among the codes used by the same coder in different instances.[33]

Third, segmenting and coding the design process is *labour intensive*. The remedy is to extract large segments, which permits analysis of longer designing episodes. This relates to our proposition of judging sketching episodes as the external representation (outcomes) of the thinking process hypothesised to capture the structural units of reasoning through coding the relations between design moves and activities and construct the linkograph.

[33] The term 'inter-coder reliability' was introduced by Goldschmidt (2014: 33-34) to describe the limitation of protocol analysis. Other causes include: *incomplete reflection of thinking processes*, *possible interference with normal thinking patterns*, *protocol analysis is labor intensive*, *delimiting the analysis units* and *ambiguity in verbalisation*.

4.4.2 Qualitative Judgements for the Sketching Episodes

The qualitative approach to judging sketching episodes considers design a *perception-in-action* process (Tschimmel, 2010). This concern is required to distinguish between *imagery* and *perception* in the thinking process (Pylyshyn, 1973; Kosslyn, 1994). Also, it is associated with examining the relation between *visual reasoning* and *design sketching* (Goldschmidt, 1994; Suwa and Tversky, 1997), and the need for *intermediate representations* (Qin and Simon, 1992). These views varied according to which research paradigm they stem from.[34]

The purpose of this approach is twofold. First, it sets up the *starting* and *ending* of what is often called a design *move* or *utterance*. Second, it aims to unveil cognitive mutual reflections with instantaneously externalised design artefacts all through various modes of representation (artefacts are the interim products such as sketches, 3D models). We aim to illuminate *stimuli* responses with respect to the sketching episodes; how they help the designer to break away from a *frame of reference* (which may lead to fixation) to proceed to a new one. The linkograph can then be drawn according to the judgements of dependency relations. While *cross reflection* is an imperative for understanding the sketching interoperability with the mind, *instantaneous perception* is also a design process included in judging the sketching episodes. Tschimmel (2010) suggests design as a *perception-in-action* process has five *non-linear* intersected procedures: *the perception of the task, the perception of a new perspective, the perception of new semantic combinations, the perception in prototyping,* and *the perception of users' reactions*. See Abdelmohsen and El-Khouly (2009) modes of 'representing the reflective practice.'

The distinction of *mental imagery* as a prime element in the design cognitive process has been taken into account while judging the dependency relations, which in turn leads to the appearance of responsive actions that might have not existed throughout a concurrent perception at the moment. This can be explained as a sign of a subconscious visual memory recalled from the back of the mind while sketching: a motor activity operating in parallel to conscious activity (Akin and Lin, 1995).

Hence, we define a *sketching episode* as a transformation in perception from one state to another while marking out the drawings before the design situation and to the interim reflection with the sketch still in progress. Any sign that the designer has perceived a notion to break out of a frame of reference and shifted to another is considered an insight according to Akin and Akin (1996). A *creative insight* moves the perception completely to a different state that is independent from the current design situation. The design moves are hence coded based on two sets of contribution: actions preserve continuous reflections in the mind and actions defy continuous reflections.

Sternberg (1999, 2003) introduced the propulsion theory of creative contributions, which indicate rates for actions of the thinking process that can be implemented to describe and code design moves of sketching episodes. In his exposition, creative actions reflect different levels of contribution that are categorised into three major groups according to their 'creative quality':

> A creative contribution represents an attempt to propel a field from 'wherever it is' to 'wherever the creator believes the field should go'. It moves a field from some point to another (Sternberg, 1999: 125).

Preserving reflection proceeds on the initial concept. It takes various forms of activity, such as *replication*, *redefinition* or *advanced incrementation*, in the same design state. *Defying reflection* introduces a new item to the current state or rejects it completely. It has a different taxonomy of actions

[34] Qin and Simon (1992) revealed an important point on the role of *intermediate representations* in the transformation of *imagery*. They conducted a study on a group of students unfamiliar with the subject asking them to understand the first part of Einsteins' 1905 paper on special relativity and stated that an *intermediate* representation exists each time the subject plans to transfer the initial text (brief) into final outcomes (relativity equations). This highlights the role the structure and specifications of the design programme (brief) may play in directing the problem-solving process into certain solutions.

Akin and Akin (1996) advocated, however, that human cognitive abilities are not only *representational* as Qin and Simon concluded, but can also be *procedural*, relying on the person's expertise. Pointing at a process of 'generation-test' – technical rationality paradigm – to structure the procedural strategy, they admit the *reductionist* view, stating that the strategy of problem-solving is about decomposing the problem into subcategories making pairwise integration of sub-solutions. They advocated that creativity is synthesised, but pointed out that in a 'restructuring' state (when design is reformulated) if severe failure is experienced while restructuring the problem, that failure will be reflected in the solution.

that operate to change the design situation, e.g. *divergence, synthesis* and *reconstruction*. *Integrating reflection* attempts to converge multiple paradigms and reflects convergent thinking.[35]

Sketching is an act to perceive and reflect cognitive actions since it plays a central role in transferring notions in the mind into a design configuration. Goldschmidt (1994) described two types of sketching: type (1) aims to transform imagery into new forms or combinations and is a rational mode of reasoning; type (2) is sketching to generate new imagery of forms in the mind and is a non-rational form of design thinking. Our proposition primarily adopts all the preceding elements into developing a qualitative model to assess sketching episodes (see Figure 4.10).

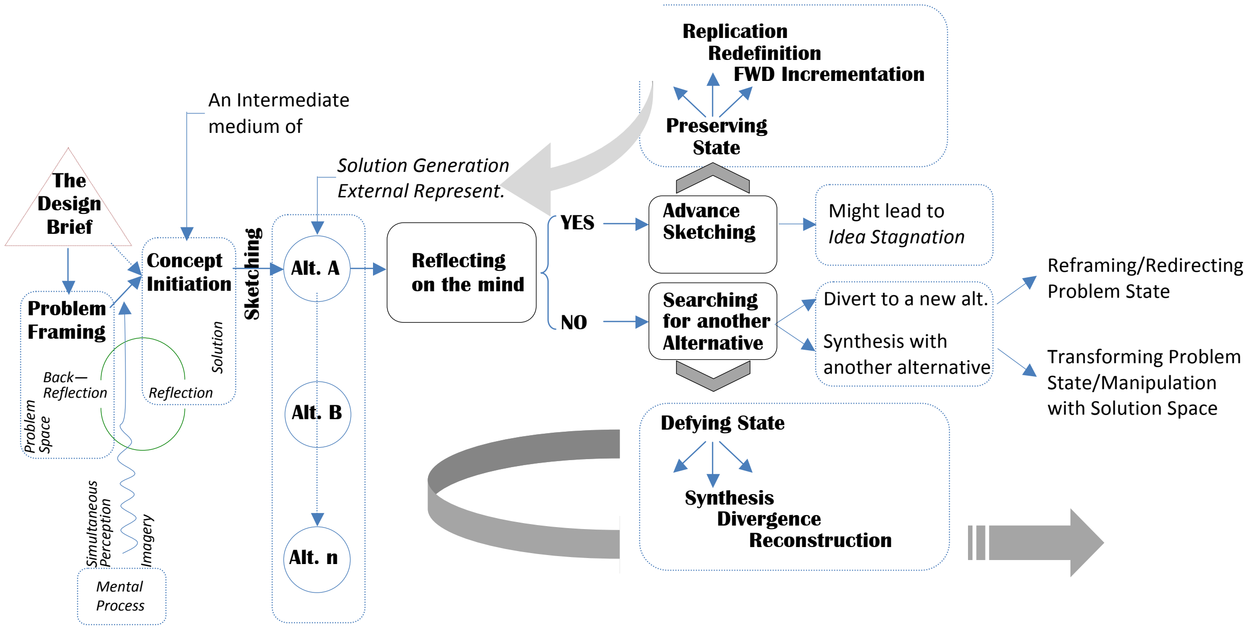


Figure 4.10 Qualitative judgements model to describe sketching episodes

4.4.3 Sketching a Design Parti: Why is Freehand Sketching Important?

Weisberg (1993) was first to note the *unexpected discovery* of freehand sketching, which helps the designer to promote creativity in design thinking in several ways, e.g. sketching to find *unintended consequences*, the surprises that keep the design exploration going to 'reflective conservation with the situation', which characterises design thinking (Schön and Wiggens, 1992); a dialogue between *seeing that* (the reflective criticism) and *seeing as* (the analogical reasoning and reinterpretation of the sketch that provokes creativity), known as the *dialectics of sketching* (Goldschmidt, 1994).

Sketching helps the designer to make not only 'vertical transformations' of a design concept, but also 'lateral transformations' within the solution space: the creative shift to new alternatives (Goel, 1995). It serves at least three purposes: as an *external memory device* in which to leave ideas, as *visual tokens*; a source of *visuo-spatial cues* for association of functional issues; and as *physical setting* in which design thoughts are constructed in a type of situated action (Suwa, et al., 1998a, 1998b). A 'skilful sketcher' is the one who benefits from the externalisation of mental imagery (Verstijnen et al., 1998).

Reinterpretation and *unexpected discovery* become the driving force to explore new ideas in sketching. They introduce discontinuity in problem-solving processes, which is a key to 'creative problem-solving' (Weisberg, 1993). Sketching engages the designer's mind into problem-framing patterns more than other tools (Gül and Maher, 2006a; 2006b). It does not limit the designer to engaging with one strategy for problem-solving, as we will investigate in the empirical study of the primary experiments in this dissertation. Rather, it is assumed that while some architects start with *framing* a

[35] The three levels of contribution are utilised in the empirical study of Chapters 6 and 7 to segment and code the design experiments. Chapters 6 and 7 bring empirical evidence of Sternberg's identification of creative contribution through the segmentation and coding of primary design case studies. (Refer to Appendices 6.1, 6.2, 6.3, 7.1, 7.2 and 7.3 for transcription, segmentation and coding).

problem, *generating ideas*, and evaluate the outcomes, others try to make *associations* between several conceptual elements, and *generate syntheses* for concept development by *reflecting*. These variations concern our investigation on procedural and contextual components in the design processes.

4.4.4 Gradual Transformation of Mental Images via Sketching Episodes

Goldschmidt (1994) offered two reversed processes of sketching: *sketching from imagery to generate new forms of combinations*, and *sketching to generate new imagery of forms in the mind*, which paved the way to compare between modes of reasoning. The *rational* mode is characterised by the systematic exchanges of *conceptual* and/or *figural* outcomes of sketching, while the *non-rational* mode causes an interactive manipulation with imagery. Goldschmidt states, however:

> Architects engage in sketching once receiving the design brief tending to solve the problem. They generate forms, not only representing mental images but also create visual displays inducing images of the entity that the design was initiated from (Goldschmidt, 1994: 158).

Investigating possible associations between ‘visual reasoning’ and ‘simultaneous reflections’ is another way of rendering our comprehension of *creative cognition* during design processes. There are different scenarios on the ‘evolution of creative ideas’ and ‘displacement of concepts’ that consider the design process is structured with information, reflections, knowledge transferral from one medium to another that may lead to the discovery of unexpected solutions, and occurrence of mental insights. The ‘evolution of thoughts due to displacement of old concepts into new situations’, first put forward by Schön (1963), is one of the scenarios that met wide acceptance in the area of research. This proposition aims to capture the ‘gradual transformation of mental images’ by segmenting the design process into quality ‘sketching episodes’. It is pertinent to understanding the displacement of concepts from one state to another in the design process, distinguishing between mental imagery and perception, and visual reasoning.

- **Displacement of Concepts**

Schön (1963) reported that an old concept acts as a *projective* model for new situations, describing the relationship between the old concept and new situation as a kind of ‘intimation’, that is, a ‘symbolic’ relation between the *old* and *new* according to a subconscious way of thinking. With the intimation of the symbolic relation, the old concept is taken as a programme for exploring the new situation. Once a symbolic relation is revealed, an indefinite number of possible related aspects of the new situation can be generated and considered.[36]

Mental imagery is recalled from memory when perception of a current idea strikes a chord with one of those stored ideas. The recalled idea synthesises with the current representation and transforms it, which reflects a ‘projective analogy’ that is necessary to the gradual transformation development through intermediate representations. Schön debated:

> If an old concept ‘A’ acts as a projective model for a new situation ‘B’, then ‘A’ is found in ‘B’ and ‘A’ is seen as it had never been seen before. An insight is to change the way ‘B’ is perceived; ‘B’ comes to be perceived as an outgrowth of ‘A’ (Schön, 1963: 88).

- **Mental Imagery versus Perception**

Pylyshyn (1973) has profoundly studied ‘visual mental images’, arguing that characterising ‘what we know’ primarily requires posting abstract ‘mental structures’ to which we do not have conscious access, because mental structures are ‘conceptual’ and ‘propositional’ rather than ‘sensory’ or ‘pictorial’. He said that *mental imagery* cannot be considered a theoretical construct to describe memory representations because they are symbolic descriptions not images in a figural sense.

In support of Pylyshyn’s findings, Kosslyn (2006) also studied mental imagery and stated that ‘imagery is not a single unified phenomenon; instead it consists of a collection of distinct functions, each of which is responsible for a different aspect of imagery’. He decomposed imagery into four sets of

[36] ‘My chief point for the moment is that the displacement of concepts gives rise to new hypotheses not only by permitting elaboration of a single metaphor, but in series of hypotheses, designs, and the like, each of which functions as a projective model for the succeeding one’ (Schön, 1963: 92).

processes: (1) *generating the image* in the brain (activating information stored in long-term memory and constructing a representation in short-term memory); (2) *inspecting the object in the image* (reinterpreting it); (3) *maintaining the image over time*, and (4) if required, *transforming the image* (rotating it, modifying parts, changing colours etc.). *Imagery* is recalled from memory but *perception* is a simultaneous reflection that is enriched during the interplay with representations (Kosslyn, 1994). Having extended the research on *visual display design*, he forwarded that 'visual displays' are based on 'psychological' principles of perception.

- **Visual Reasoning**

Design is considered a *visual reasoning process*, which is structured with simultaneous perceptions occurring along the way with the representations. It is necessary to understand the relation between visual reasoning and interactions with design artefacts through sketching to understand the reflection-in-action process. Tschimmel (2010) took a step forward associating design as 'perception-in-action' that corresponds to the 'simultaneous interaction' with 'representations'.[37] If design is considered a 'simultaneous visual reasoning process' where the manipulation with artefacts plays a vital role, then *visual imagery* can be considered a pattern of 'pictorial reasoning', which displays the gradual shifts between two modalities of arguments; *figural* and *non-figural* aspects of candidate forms at the time of initial generation (Goldschmidt, 1994). Figure 4.11 illustrates that mental imagery is recalled from memory while perceiving insights from simultaneous perception with interim representations to indicate the visual reasoning process.

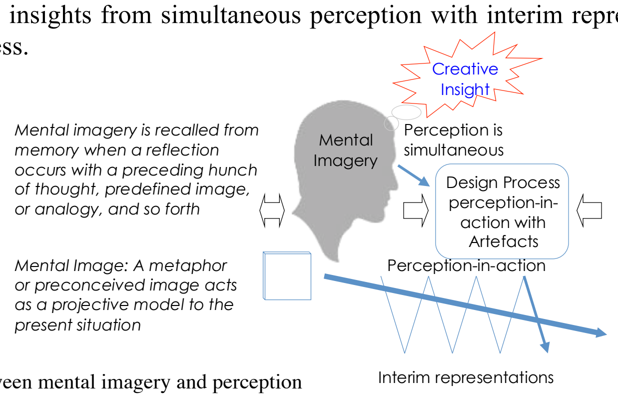


Figure 4.11 The difference between mental imagery and perception

Visual reasoning is necessary to understand the transformation of ideas from one state to another. In this proposition, we aim to capture the segments of sketching episodes that reflect the visual reasoning with the artefacts. Sketching episodes result from the interactive reflections between the mind and drawings. They signify the gradual transformation of mental images, ending when satisfaction of sufficient coherence is achieved. With the dialectics of sketching representing the oscillation of arguments in the design process, the structure of reasoning can be characterised in terms of 'sketching episodes of gradual transformation'. The objective of identifying the prototypes of *reflection* in this process is threefold: first, investigating the *structuring* or *restructuring* of the *solution domain* (Akin, 1990), second, examining the *representation of domain-specific knowledge* (Chan, 1990), and third, exploring the means of activating *design constraints*, associations of *rules in memory*, and *design ability*: the ability to select rules in schema (ibid).

The evolution of ideas and creative insights is assumed to result from the reflections with the artefact of sketching. This has been investigated in Balfour's study *The Evolution of Decorative Art* (1893, cited in Steadman, 2008: 101), which conducted some experiments on *imitation*. In this study, each experiment started by drawing a concept sketch; each participant was requested to 'imitate immediately the preceding sketch without reference to the original'. Resulting in a series of sketching episodes, with different degrees of alteration between each pair of sketches, the final result showed extreme alteration from the original concept in most experiments. This alteration is the result of the *perceptive interpretation* of each person. Each of those sketching episodes reflected a distinctive concept on its own; as understood and sketched by the artist once the previous sketch was viewed, which Balfour referred to as *unconscious transformation* (see Figure 4.12). Although there is a gradual transformation, there are some (or few) intermediate events in the sequence that can be inferred as central hinges of

[37] Tschimmel (2010) distinguished different categories that perception might take while solving the design problem, e.g. perception of *task*, perception of a *new perspective*, perception of a *new semantic combination* (synthesis), *in prototyping*, and perception of *user's reaction*.

transformation, seen vaguely as one concept or the other. These central events reflect a change in the cognitive representation allowing a drastic transformation to take place. Balfour debated that this sequence of imitation signifies evolution in its simple form.

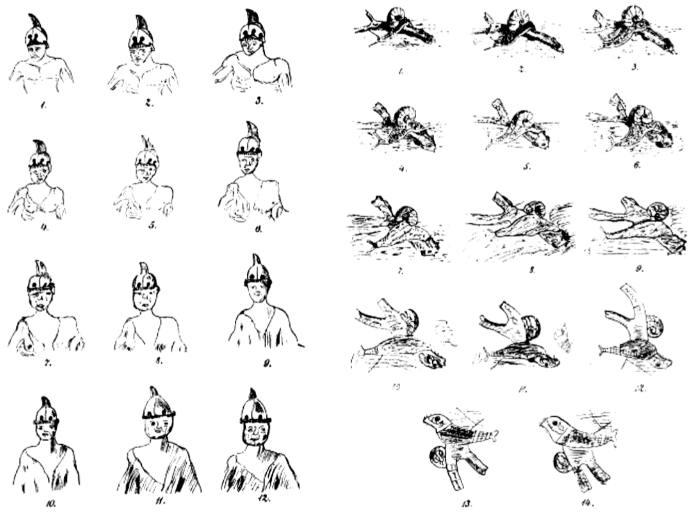


Figure 4.12 Balfour's experiments on *imitation* showing the alterations in sketching episodes to the perceptive interpretation of unconscious transformation: (left) Aegina Marble, (right) a depiction of a snail crawling over a twig
Source: Balfour 1893, reprinted in Steadman, 2008: 101.

4.5 Pilot Case Study 3 on Architectural Design Process: The Phase of Early Initiation of Conceptual Ideas

We will look first at the brief given to the designer, a chartered architect from Greece with 12 years' experience, in a design experiment at Bartlett School of Graduate Studies, University College London, and the products designed. The compatibility between the segmentation and qualitative results is the centre of attention to assess the adequacy of this proposed scheme.

Design Brief: The designer was requested to design a pavilion at *Expo-Shanghai* 2010. The aim was to present the 'image of your country according to your own perception'. The brief was deliberately left open-ended with no specific requirements, constraints or regulations, in order not to direct the designer to a specific resolution. The designer was asked to present the conceptual idea freely via any means of representation without any specific drawings or projections being requested and with no intrusion from the researcher supervising the study. The process was video-recorded (with designer's written consent) to verify all the interactions and activities. After one hour, the designer was asked to explain the design idea retrospectively with respect to the serial order of sketches (three A2-size sketches were produced in this session, see Figure 4.13).

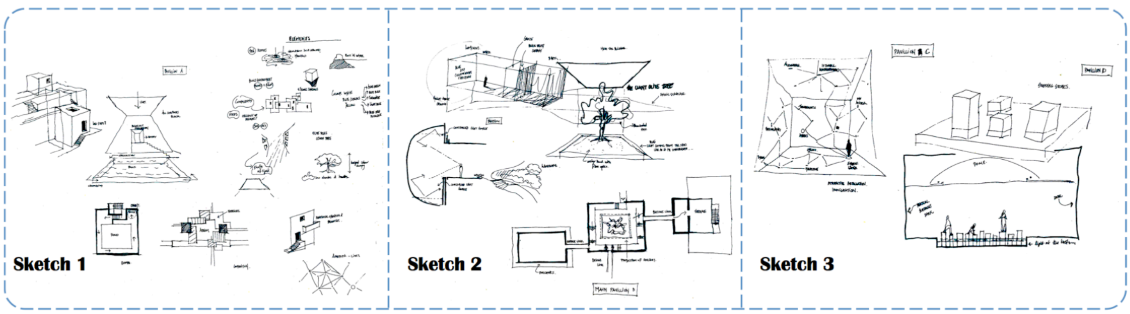


Figure 4.13 Sketches from the design experiment of Pilot Case Study 3

4.5.1 Segmentation of Sketching Episodes

The dependencies between design utterances were examined and coded according to the order of occurrence of interim artefacts (sketches). To summarise this proposition, coding relations in a linkograph were mainly based on checking the states of appearance and absence of changing concepts, representations, functions, the reasons for new fittings and installations, the variations in spatial configurations, and so forth. It was predominantly about tracking the reflections in their order of occurrence in the context of the interim productions of artefacts to construct an adequate linkograph.

The following section presents a procedure to integrate segmentation and coding with qualitative judgements in an approach to build up an objective tool to describe the design process. Table 4.4 presents the procedure and order of analysis in the proposed model by integrating qualitative and quantitative approaches.

Table 4.4 The integration of qualitative and quantitative approaches in one model

#	Phase	Detail
1	**Transcription**	Transcribing the design activities accordingly to the time of occurrence
2	**Interim artefacts**	Setting out the interim outcomes in the order of emergence (design artefacts, sketches, etc.)
3	**Identification of design episodes**	Processing the qualitative/cognitive model by identifying each design move according to the notion of ‘reflection-in-action’
4	**Coding process**	Coding the relations between the externalised drawings and activities. In this phase, the dependency relation is looked at through two angles: 1) The relation between each pavilion and the first set of design elements (the interim artefacts and initial conceptual elements) 2) Pairwise comparison between sequential pairs of drawings. This is to investigate the lateral transformation and search for any sudden insight that might occur in the prevailing flow
5	**Reflection-in-action**	Finding the ‘reflections’ and ‘back-reflections’ amongst the sketches to classify a hierarchy of the products
6	**Linkography**	Drawing the linkograph
7	**String computation**	Processing the quantitative model (T-code measures) - Setting out a matrix of relations - Processing the T-code algorithm
8	**Archiography**	Drawing the archiograph (another representation of the linkograph but it reflects the relations in a clearer way)
9	**Comparisons**	Comparing the archiograph with a hierarchical classification of the interim artefacts
10	**Correlations**	Checking out if correlations exist between the quantitative model and qualitative judgements

4.5.2 Identification of Sketching Episodes

Our aim is to adjust the segmentation of the design episodes in order to avoid any minor or trivial actions and detect the critical events that reflect the structure of reasoning process. Our approach uses the ‘sketching episodes’ to capture the ‘graduation transformation of mental images’. As external representations of the mind, sketching is associated with reflection-in-action and design reasoning. This scheme identifies the *starting* and *ending* points of sketching episodes as follows:

First, a sketching episode is determined when the designer ends the execution of a conceptual idea during ‘one-go’ sketching activity. Any occurring alteration in the course of sketching this idea is considered a starting point of a new episode (segment), even if it preserves the flow of the original idea, e.g. sketching another projection for the prevalent concept.

Second, the initiation of an entirely new sketch is a starting point for a group of activities that subsequently may include several designing episodes. Once a transformation occurs that moves the design from one state to another, an episode is identified and so forth.

Third, designer's idiosyncrasies can be detected during the execution of the idea through sketching, thinking etc., e.g. rendering the conceptual elements of the idea to emphasise it, mirroring or flipping the design configuration to reconfigure the spatial organisation, zooming in/out, adding details, tracing elements from one drawing to another. Thus, we aim to detect all the possible critical actions that contribute to the creative quality and initiation of concepts but to adjust the level of segmentation to capture the real state of design. Figure 4.14 presents snapshots of sketching episodes of different creative qualities. Figure 4.15 shows the alternation between different sketching episodes, which constitutes the qualities of either preserving or defying the concept from one state to another (*transformation* versus *drastic change* occurring in the *flow of sketching*).

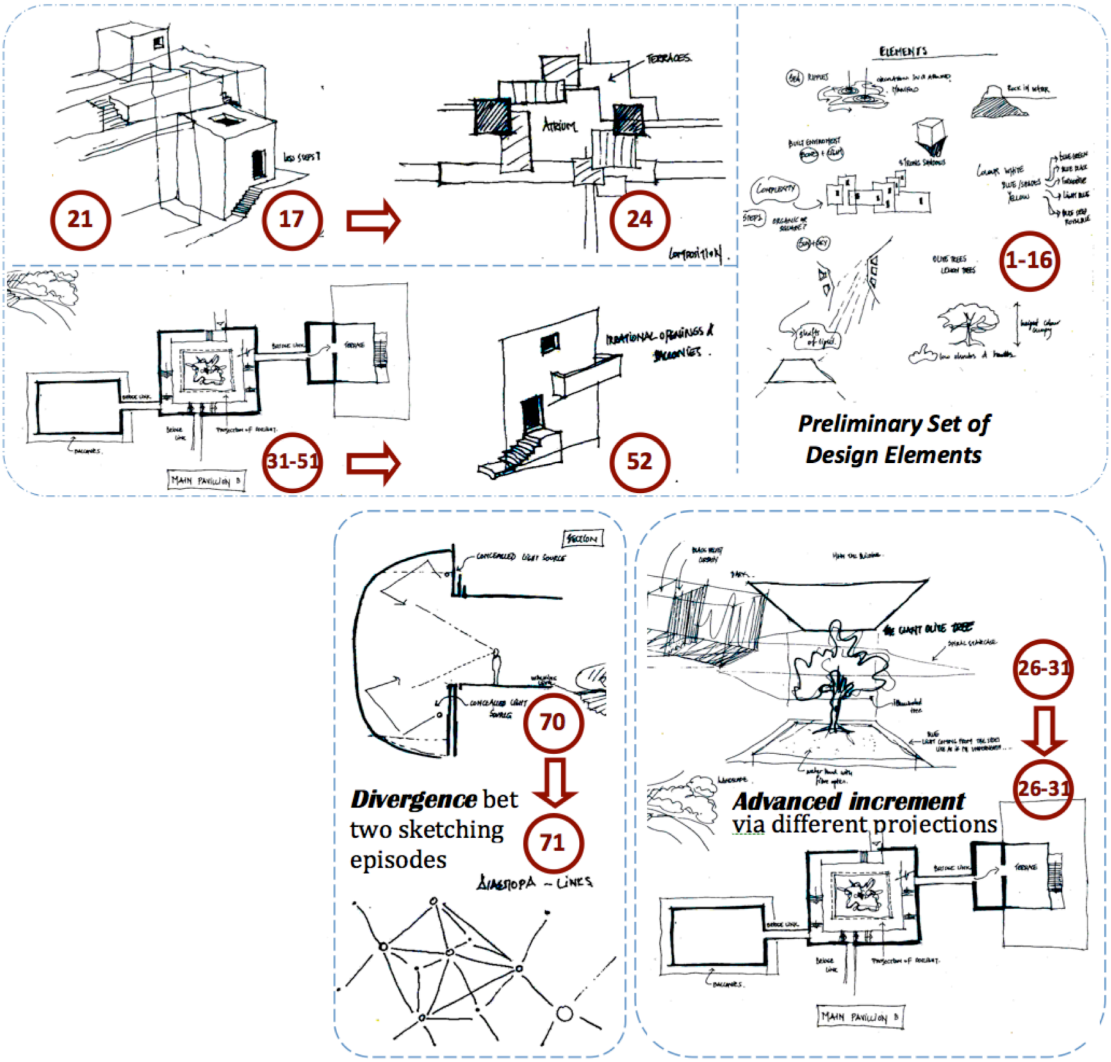


Figure 4.14 Segmenting sketching episodes of different creative qualities

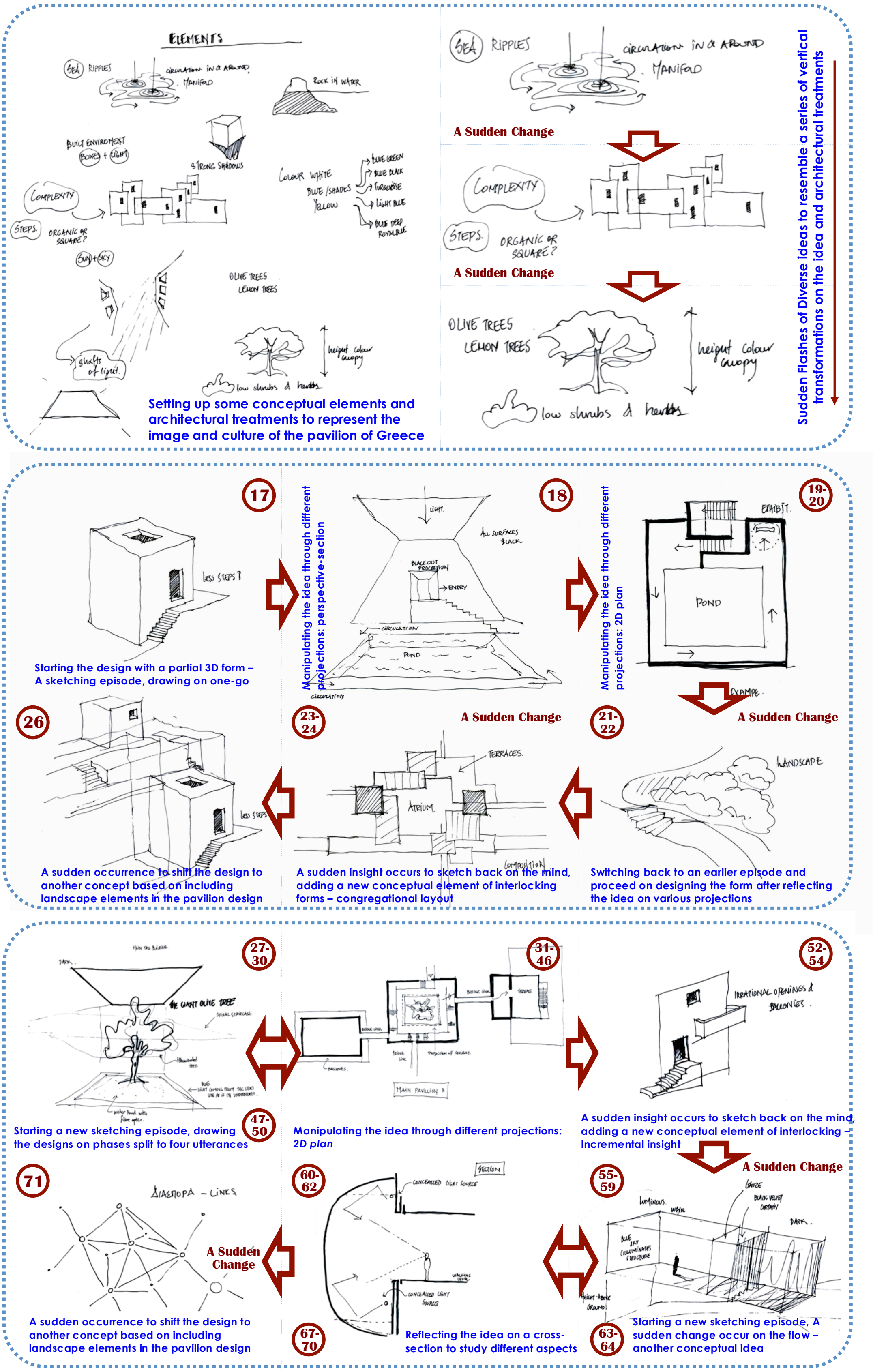


Figure 4.15 Identifying the sudden changes occurring on the flow of sketching episodes

4.5.3 Coding the Dependency Relations

Design moves are coded into sets of creative contribution: actions that ‘preserve’ continuous reflections with the mind and actions that ‘defy’ continuous reflections. *Preserving* reflection proceeds from the initial concept taking various forms of activity, such as *replication*, *redefinition* or *advanced incrementation*, in the same design state. *Defying* reflection introduces a new item to the design state. It has a different taxonomy of actions to change the design situation: *divergence, synthesis* and *reconstruction*. This model is built on the range of transformations that a design idea is susceptible to. Creative insights are determined and judged according to this qualitative framework. Figures 4.16 and 4.17 illustrate snapshots of the coding among the structural units of sketching episodes.

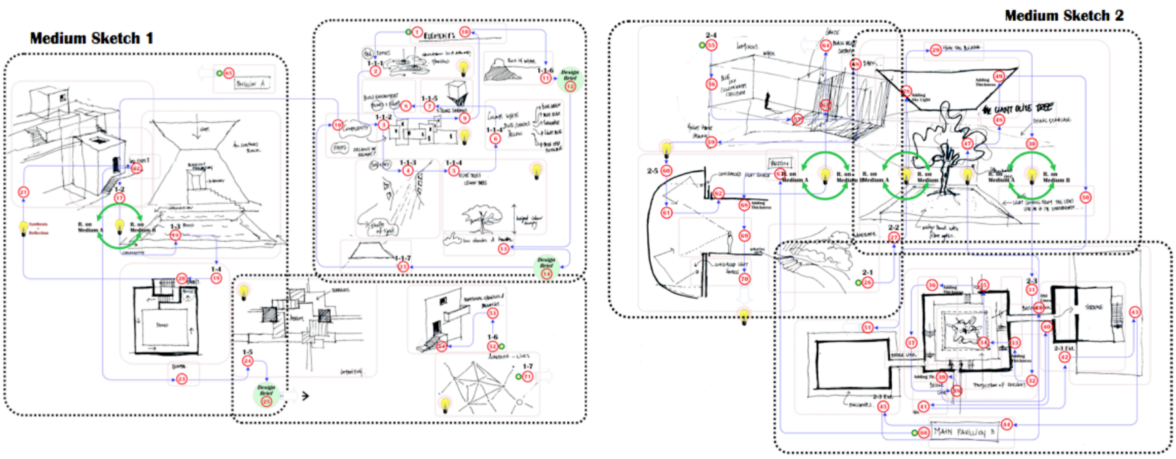


Figure 4.16 Coding different sets of drawings and sketching episodes considering the order of occurrence and reflective practice

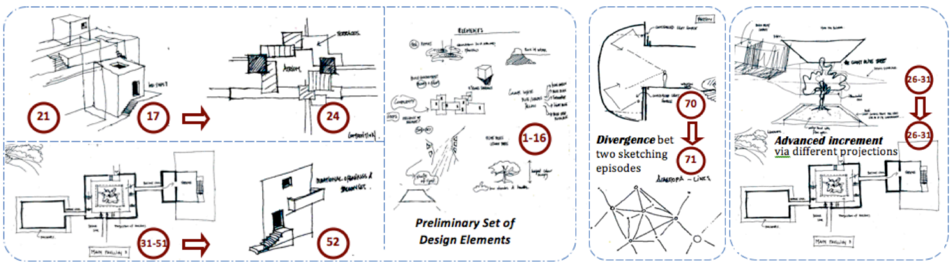


Figure 4.17 Procedure of coding the sketching episodes and transformation of ideas forming utterances of the design linkograph

- **Example: Design Situation One**

This design situation reflects the transformation of concept where a decision was taken to form the master layout from interlocking masses (which symbolise the Greek archipelago) and congregate the parti around a central patio. The execution was made on a series of designing episodes (across three projections) (Axonometric, Perspective Section, and Master Plan) (see Figure 4.18). Segment 17 is a starting point for the axonometric but this episode was not completed: the designer shifted to sketch a perspective-section at segment 18. Halting the sketching for a few seconds, a new segment 19 occurred where the decision to add a central pond to indicate water as a natural resource was made. The idea was developed through 2D plan at segments 20 and 21. The designer went back to complete the axonometric episode in a new sketching episode 22. Thus, the creative quality for this group of design episodes is 'advanced incrementation'.

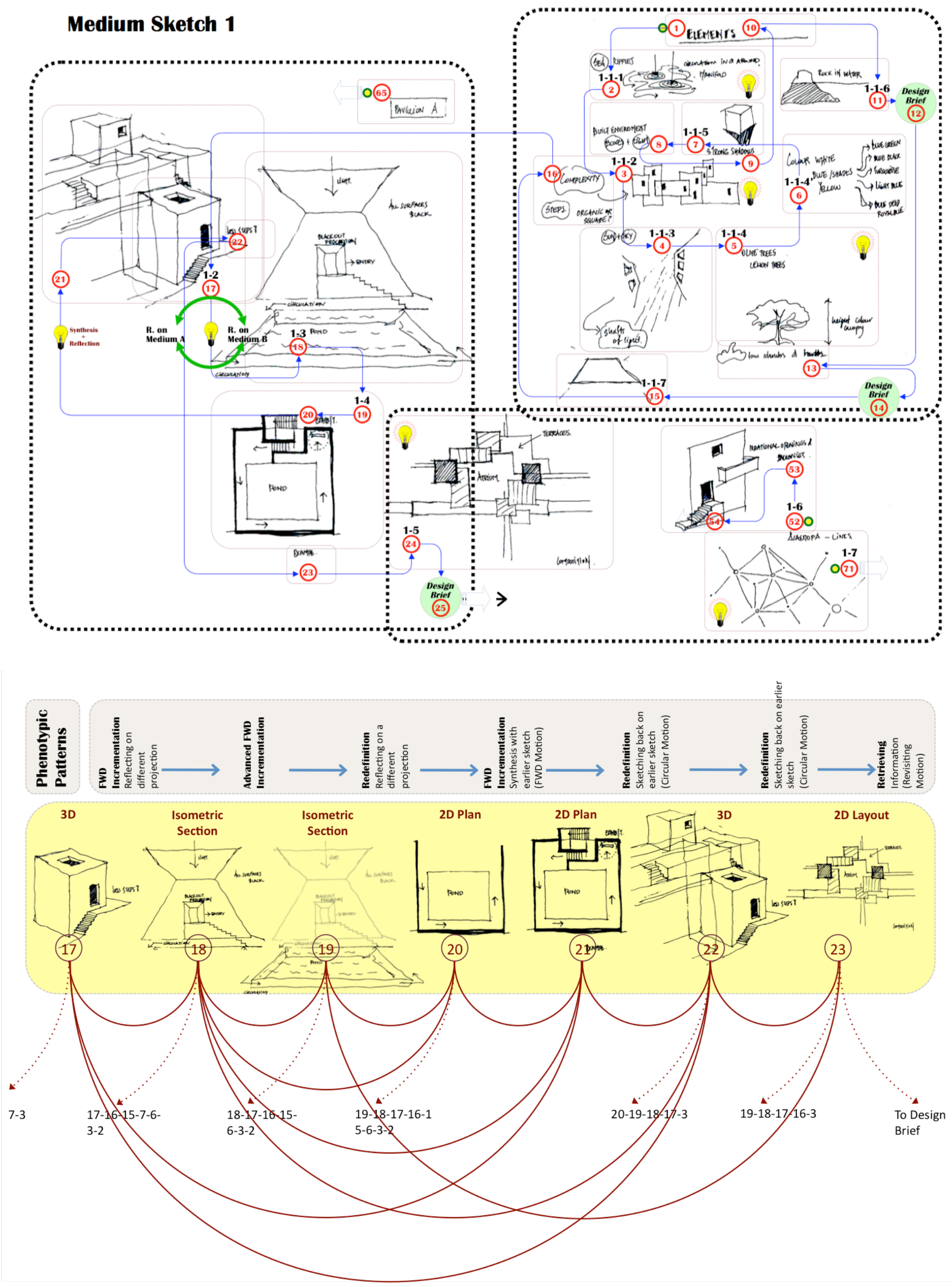


Figure 4.18 Coding sketching episodes (17:23) contributing to 'advanced incremental' development of the concept

- **Example: Design Situation Two**

This design situation created synthesis between two conceptual ideas: the element of green landscape (the lemon or olives trees popularly planted in Greece), and the pavilion of the central patio, interlocking forms and pedestrian bridges. The design took a procedural approach, a series of stages, each of which is visited only once (as defined by Wynn and Clarkson, 2005: 41)[38]. In this situation this approach halted the sketching process to add detailed after pauses for thought. The creative quality for this group of design episodes is 'redefinition', associated with accelerated forward motion based on the original concept (enriching the concept with new elements to add the value of embedding elements from the nature) (see Figure 4.19).

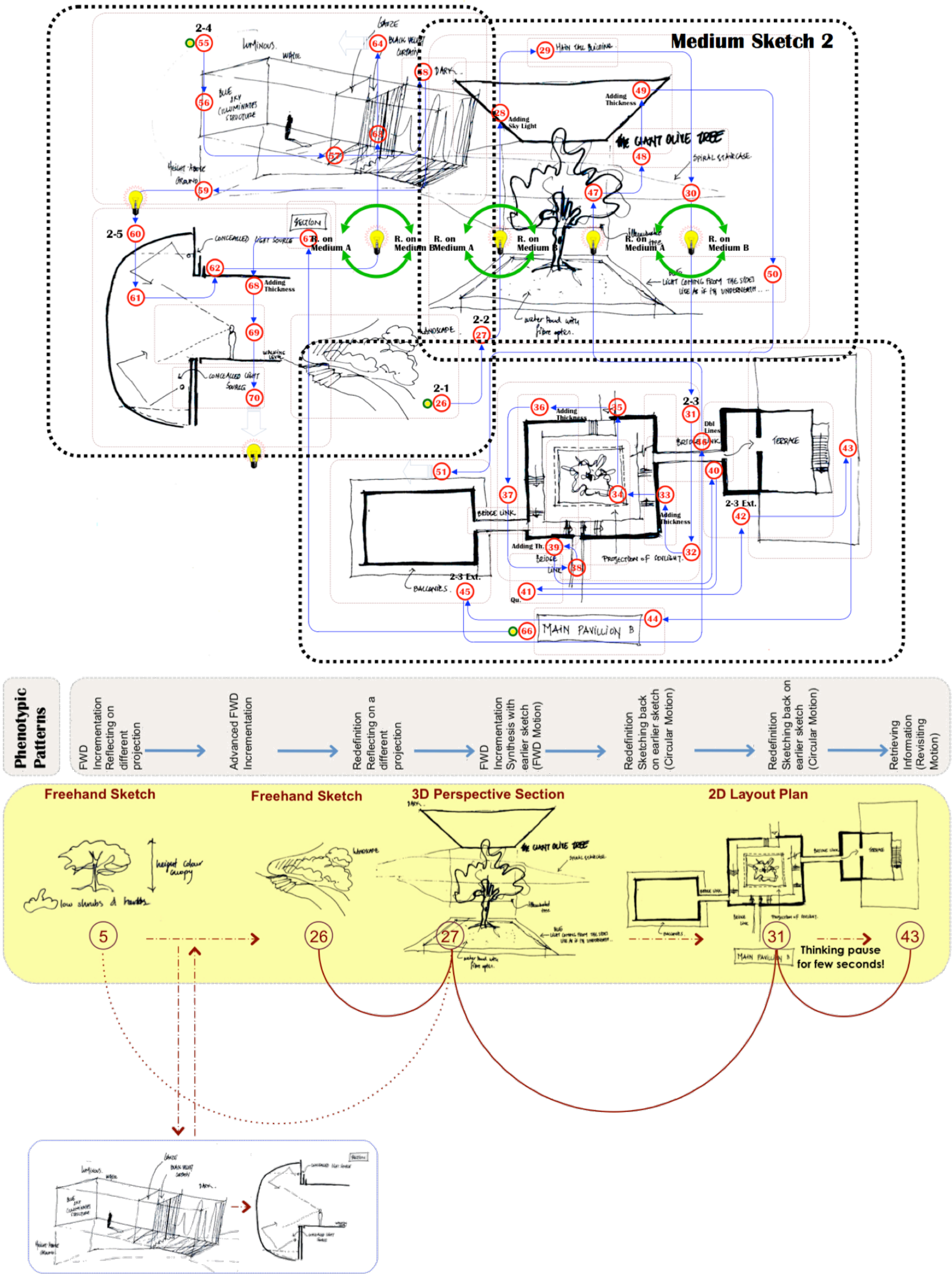


Figure 4.19 Coding sketching episodes (5 and 26:43) contributing to redefine the concept with synthesis

[38] Evans (1959) proposed another approach: a combined 'stage and activity' model concentrating on the iterative nature of the design process, arguing that it is difficult to achieve the design by following a linear process. Refer to the Abstract, Procedural and Analytical models in Chapter 2.

- **Example: Design Situation Three**

This situation constitutes a 'drastic change', the sudden occurrence of an insight that has no relation to any preceding design actions or interim artefacts. The emergence of sketching episode 70 is entirely different from the preceding episode 69. The designer shifted from designing a section through the 'light tunnel' pavilion to designing the 'link installation' pavilion. This event provided a novel solution for the pavilion, which changed the flow to a totally different state. Another change occurred at action 79, when the concept of 'link tunnel' was entirely shifted to a different one, to design the 'rock and water' pavilion, starting from segment 79; see Figure 4.20.

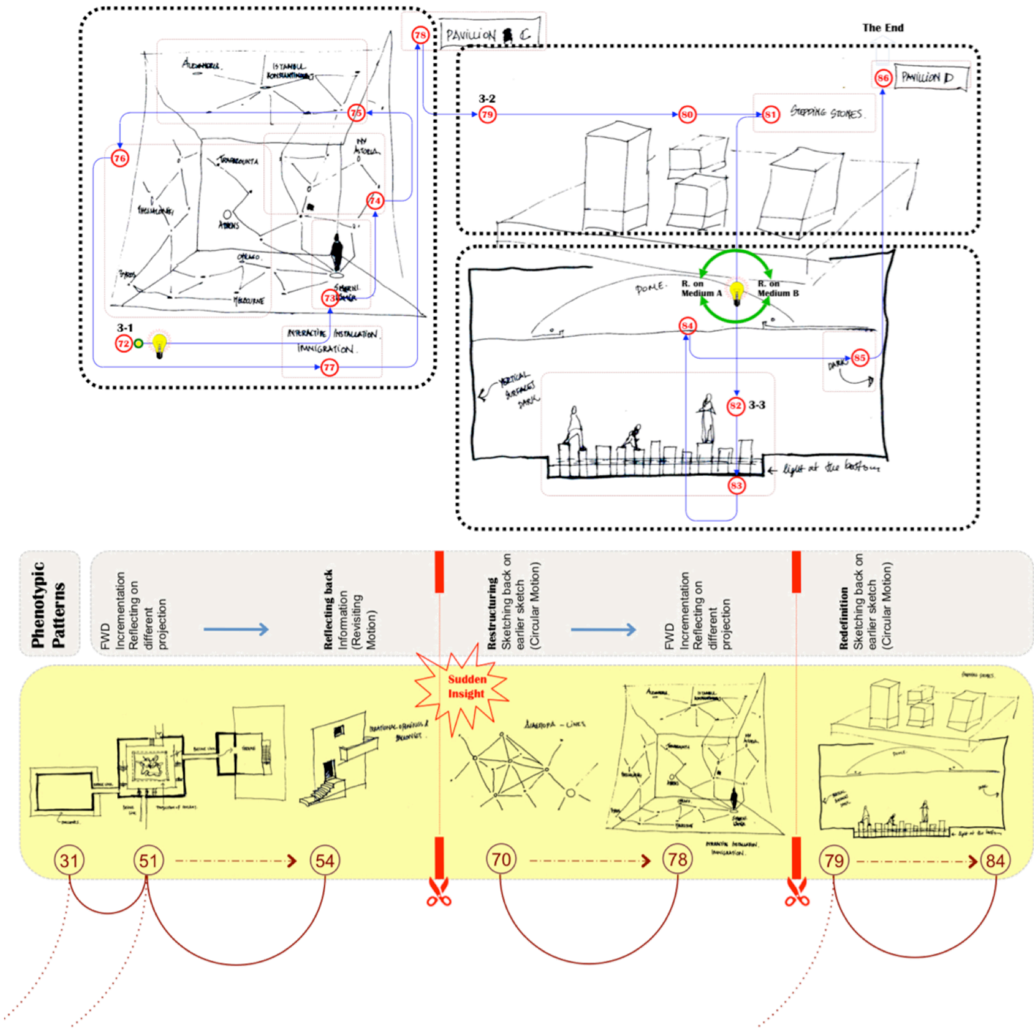


Figure 4.20 Qualitative judgement for Design Situation Three – A paradigm shift restructures the design problem, shifting to a novel concept in the flow; a hybridisation with newly addressed elements then appears at node 79 until 84 (ending nodes)

4.5.4 Identification of Sudden Mental Insights: 'Eureka!' and 'Aha!' Moment

Our proposition to consider 'sketching episodes' to signify the 'gradual transformation of mental images' and the 'reflective practice' in the design reasoning process helps to investigate the context beyond the occurrence of eureka insights. The quality of the emergent sudden action is determined by the benefit it brings to idea generation and final concept development. The value of emergent actions in the design process is discussed further in Chapters 6 and 7.

Identifying the series of events of sketching episodes determines the unitary bases to construct the linkograph, which reveals the transformation of ideas and changes occurring suddenly in the design process. This approach indicates the critical moves that may be considered creative actions if they add value to the concept development. Accordingly, this section discusses the context of emergence and definition of sudden insights, while detailed descriptions are included in the empirical study of primary design cases.

Attempts to define the evolution of ideas and formation of design concept can be categorised in two opposite views: one argues for the *mysterious* emergence of insights; the other for *reductionism*. The former considers that creative action is absolute *causeless*, *synchronic*, regardless of preceding actions, e.g. the Gestalt School. The reductionists view the emergence of new concepts as a simple recombination of old ideas through *association* (synthesis) and incremental reasoning. It traces the trajectories of preceding actions that lead to the formation of concept *diachronic*ally. This view was endorsed by Schön:[39]

> By screening out disruptive novelty, selective inattention makes for conviction, as well as for simplicity, obviousness, and sanity (1963: 88)
> …
> Some innovators combine, paradoxically, the capacity for selective attention, essential to action and the openness to disturbing novelty essential to discovery … They take a directed course while at the same time, in another corner of their mind, they attend to irrelevances, to the unexpected, to what does not fit. Innovation demands concentration on a single theme of action while other themes are held in suspense (1963: 97).

This accords with Koestler's view of the creative act to adopt the reduction theory, which inferred the occurrence of sudden insights to bisociation between different thoughts:

> I have coined the term 'bisociation' in order to make a distinction between the routine skills of thinking on a single 'plane', as it were, and the creative act, which, as I shall try to show, always operates on more than one plane. The former may be called single-minded, the latter a double-minded, transitory state of unstable equilibrium where the balance of both emotion and thought is disturbed. The forms, which this creative instability takes in science and art, will be discussed later; first we must test the validity of these generalisations in other fields of the comic (Koestler, 1964).

Akin and Akin (1996) also described the reduction theory when they explained that the emergence of sudden insights is a stimulus response to break out of a frame of reference shifting to a new one when a fixation effect is experienced. In this sense, Csikszentmihalyi (1996) defined the 'creative process' as the 'flow and the psychology of discovery and invention', and Johnson (2010) described the conception of a 'good idea' as: 'two thoughts colliding, one that has incubated for a long time in the mind with another arising from the present situation'. Chiang (2006) identified the role that eureka plays in the design process:

> Design eureka functions more likely as an effective act of changing the problem landscape into become more plausible for forming solutions, rather than as an effective solution per se. In this light, 'changing-problems' instead of 'solving-problems' holds the key to the design eureka (Chiang, 2006: 2).

To conclude, this point crystallises our understanding of the phenomenon of sudden creative insights and the context beyond emergence to be determined with one essential condition: the 'restructuring of the design problem': the 'reformulation of the entire design situation'. A *sudden mental insight* moves our perception from its instance (present design situation) to an independent state. Hence, we identify two parameters to investigate the emergence of actions in the design process and identify whether the action 'reframes the solution' or 'restructures the problem'.

The alteration from one sketching episode to an entirely different one is proposed to reflect this sudden moment shifting the perception occurring in the mind to a different state. According to our ethnographic observations on different pilot case studies, insights occur while architects reflect on old sketches from the concept initiation phase. This plays an important role in stimulating unexpected ideas, e.g. knowledge transfer between sketches, comparisons, multiple switching of designing media and tools. Figure 4.21 illustrates the drastic shifts of transiting from one sketching episode to another in one of the case studies. Although the designer initiated a zoning diagram for the expo pavilion, an idea occurred suddenly to sketch the conceptual cross-section, adding value to the emergent solution of the design's spatial configuration through the design process.[40]

[39] Schön's definition of the 'invention and evolution of ideas' (1963) as: 'treating the new in terms of the old', 'a displacement of ideas from the old situation to new one'.
[40] This example is described in detail in the empirical study of Chapter 6, Primary Design Case Study 3. See also Appendix 6.3.

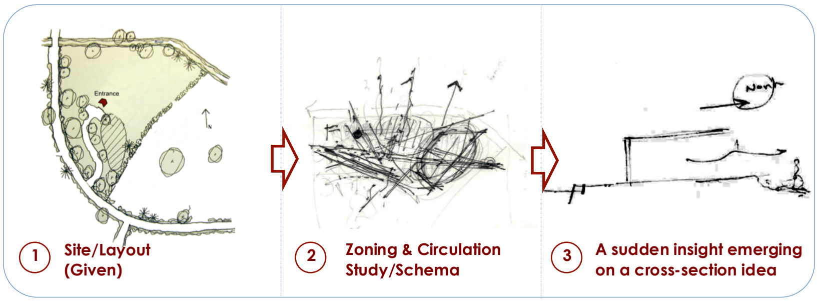


Figure 4.21 An example of drastic shifts between the sketching episodes (see Primary Design Case Study 3)

4.5.5 Linkography, Archiography and Shannon Entropy

The linkograph is constructed to reveal the structure of design reasoning from one sketching episode to another. The transcription and coding phases reviewed the idiosyncrasies and types of activities involved, which may reveal the emergence of certain concepts. Activities include 'comparing two sketches', 'alternating between design tools or media', 'synchronous viewing and exchange of information between artefacts', 'sudden reflections on artefacts'.[41] All existing actions were investigated via this scheme to assure the inter-reliability of coding. Trivial actions were omitted from the protocol so as not to flatten the linkography system. Unlike predefined coding schemes, it is anticipated this will detect the essence of design activities and designing practice.

Archiography is a graphical representation of dependency relations by looking at the relation between design moves (sketching episodes). It was developed to illustrate the relations in a clearer way than linkography (to avoid dense clusters of nodes not on the baseline). Archiography draws arcs between the related utterances in relation to their designing medium. It enables us to inspect the role of multiple switches between different products/sketches and the emergence of critical actions (sudden insights). It supports our investigation on the connectivity of linkograph to describe the structure of events via different spectrum of states: *orderliness* versus *disorderliness*. *Archiographer*© is software aimed at building relationships and drawing the archiograph (El-Khouly and Penn, 2012a, 2012b).[42]

Archiographer is developed to represent the relation between episodes in the design process to unfold the structure of reasoning, to describe single events occurring within the whole and its relation to the transformation of concept, and to capture the sudden emergence of creative insights. Network analysis, linkography and archiography are representation protocols that address the discourse of design discourse of design of *bottom-up* or *top-down* with graphic representation for the role of each element occurring in the process that contributes in the transformation of concept(s) throughout. Figure 4.22 presents the linkograph and archiograph of Pilot Case Study 3. It is overlaid with Shannon's entropy dynamic values, calculated using Kan and Gero's method (2005a, 2005b, 2005c, 2008).

It is observed that although the transcription, segmentation and coding scheme for this pilot case study is reviewed and reformed, there are some venues in the linkograph that reflect negligible zero entropy values on Shannon's scale. In addition, this method could not capture the disconnection in the pattern of linkograph that occurred at actions 70 and 79 where no indication can be tracked by Shannon's entropy values. This raises our concern again especially when those venues comprise chunks with links. Chapter 5 looks at the quantitative methods to acquire information from the design process and proposes a novel method to quantify the hierarchical structure and multileveled complexity of linkography. It also reviews hypotheses 'A' and 'B': whether creativity is associated with productivity and richness of links and can be evaluated via information entropy.

[41] Architects demonstrate specific idiosyncrasies while designing, such as *back/fore linking*, developing an idea between different projections, tracing drawings, zooming in/out, verbalisation and using confirmation words, signs and gestures, body/hand language, annotations and scribbles. All actions are examined while transcribing, coding linkography, and investigated for any insights occurring while describing the analysis for the design process.

[42] Archiographer© is scripted using *Processing*© and *Python*© by Mohamed Abdallah and Tamer El-Khouly.

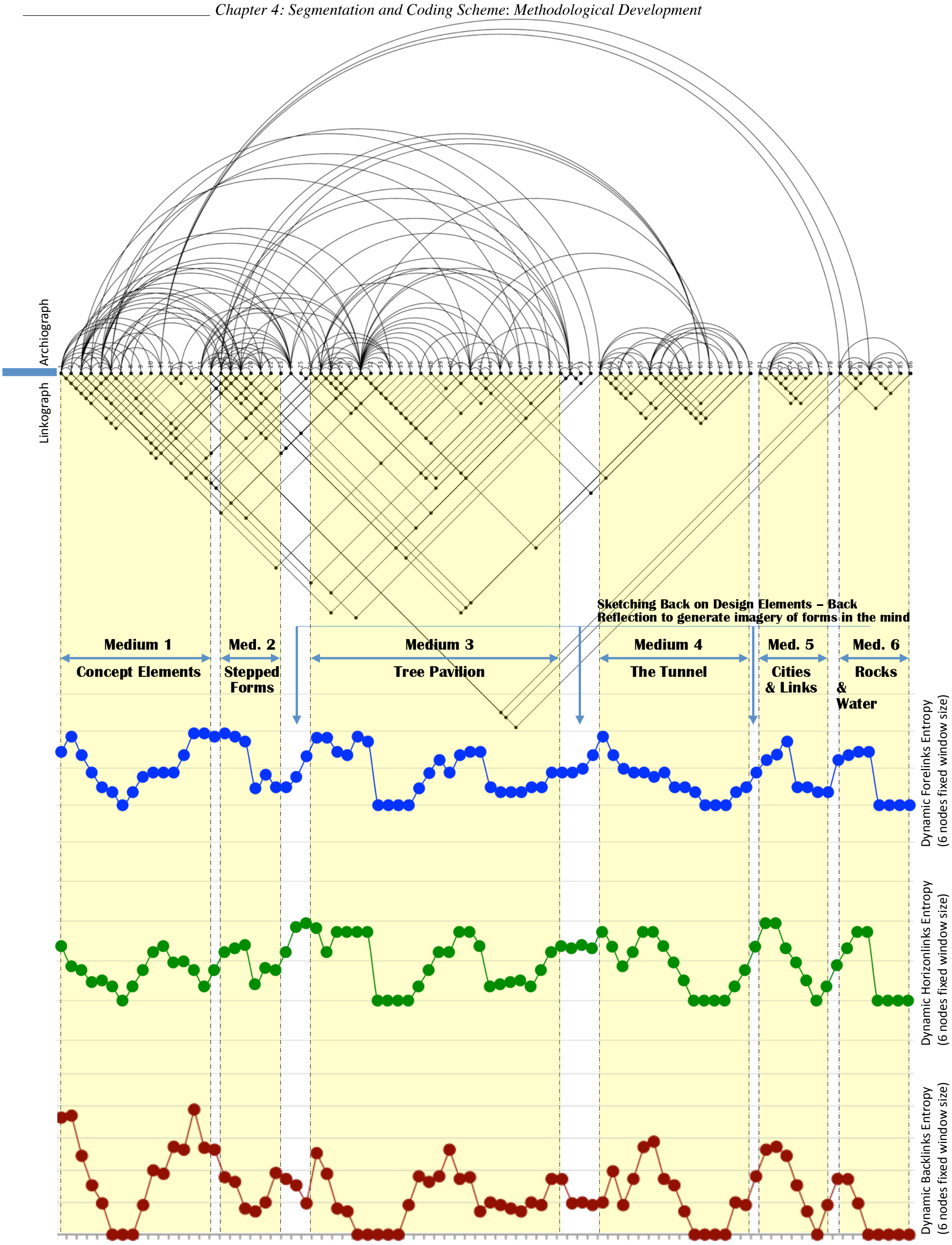


Figure 4.22 Overlaying Shannon's entropy values on the linkograph (Pilot Case Study 3)

4.5.6 Discussion

This developed scheme captures the gradual transformation of mental images and the segmentation of sketching episodes to represent the structure of reasoning in the design process. Subsequently, three levels are denoted to inspect the structure of design hierarchy: (1) the preliminary level of concept initiation (an intermediate medium of representation); (2) a level of continuous forward sketching, externalisation and execution of ideas; and (3) a level of retrospective reflections to generate imagery of forms in the mind (represented by adding new design elements to the preliminary set of concept initiation). Figure 4.23 illustrates the distribution of sketching artefacts (snapshots) across these three levels. Through this method, we can detect a multilevel concept that has been conducted through a design case study, to judge how the design serves it goals and how it sets new goals. A multilevel design concept is evolved through those three levels.

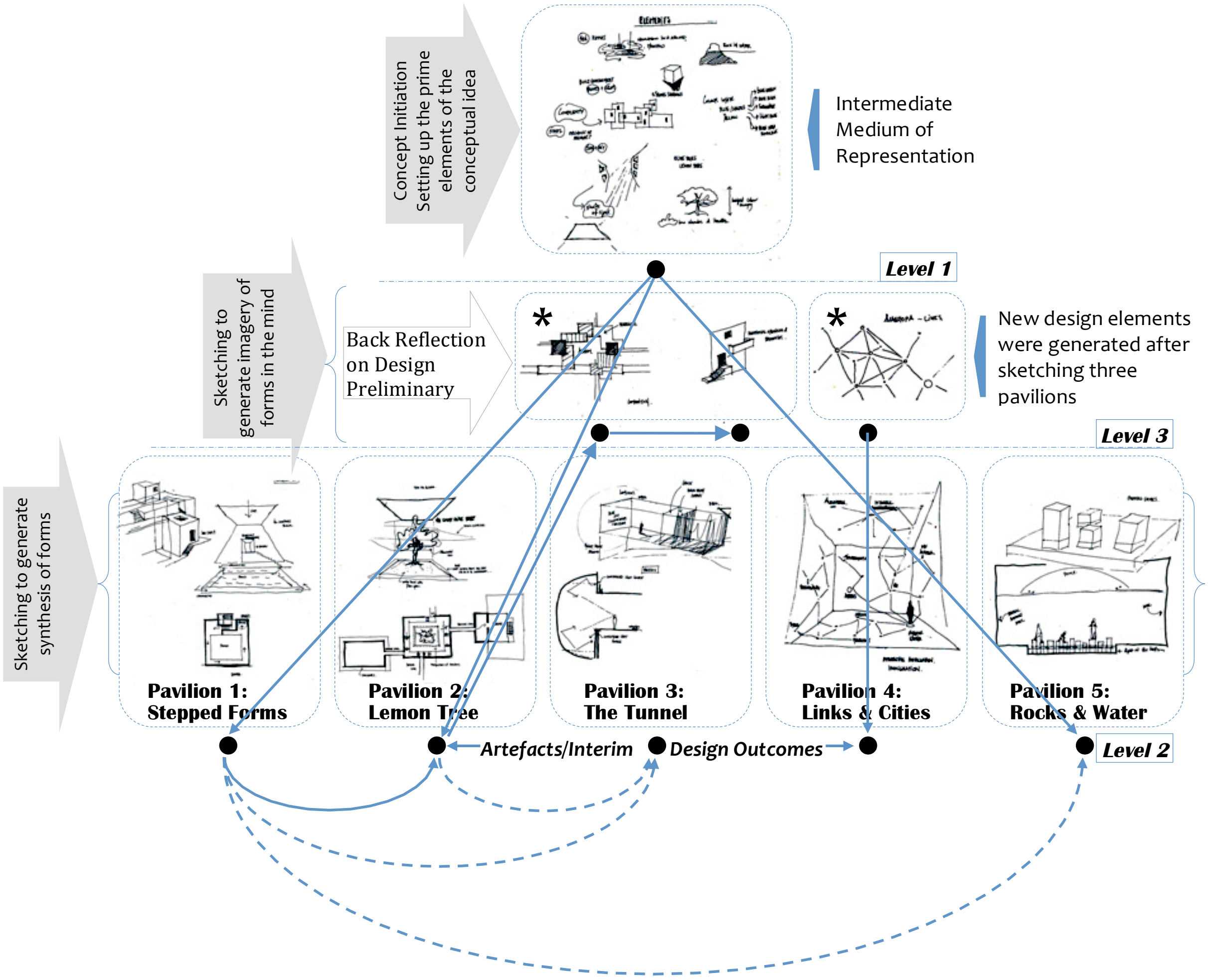


Figure 4.23 A hierarchical classification of sketches based on 'reflections' and 'back-reflections'

The identification of sudden mental insights, eureka and aha events is associated with the creative quality of the emergent action and the added value to the problem formulation, solution generation and concept development. The reliance on quantitative measures to inspect the structure of networks beyond the emergence of critical actions must be associated with qualitative judgements on the contents of design and its relation to the structure of design reasoning. The measurement of information entropy could not capture the drastic change occurring in the design process of Pilot Case Study 3 (e.g. the disconnection in the linkograph between actions 70 and 79 due to the occurrence of a different idea). Kan and Gero's application of Shannon's entropy computes one value for a whole chunk of links, which is controlled by the number of moves (segments) in each window of estimation. The disadvantages of this method are identified in Chapter 5 followed by the introduction of our proposition to acquire quantitative information from linkography through the 'string of information' and t-codes method.

4.6 In Conclusion

This chapter presented a methodological development for segmentation and coding schemes. The hypotheses of predefined schemes were introduced and examined through three pilot design experiments with different designing conditions, settings of tools and media. A method developed to capture the structure of reasoning through emergent sketching episodes was proposed to describe the design process adopting the aspect of practice. Freehand sketching is an important tool to flexibly engage with the mind and convey abstract thoughts into representations of design configuration, which in turn reflect back ideas to the mind to generate new forms.

The association between 'creativity', 'productivity' and '*richness* of links' is still debatable. Assuming that a eureka moment might redirect the whole design process into a different unprecedented solution and restructure the problem, the richness of links from this particular moment to the preceding events might be negligible. This will be indicated by a low entropy value, if not the minimum in the overall values. And hence, this hypothesis cannot be generalised on every creative event occurring in the design thinking process.

The main contribution of this chapter is that it develops a segmentation and coding model to capture the meaningful structure of reasoning and idea generation process and ignoring any unmeaningful or trivial actions that may flatten the linkography system.

Chapter 5 looks at quantitative methods to examine their ability to capture the events occurring in the design process, understand the structure of networks in the linkograph and identify its complexity. Qualitative and quantitative approaches are then examined in one framework of analysis. Our aim is to investigate creative discovery in the design processes and reveal the role of procedural and contextual components.

4.7 Key Findings of Chapter 4

- Segmentation: The adjustment of the degree of segmentation is important to construct the linkograph based on the hierarchical structure of thoughts to avoid flattened or dense networks.
- Coding: The gradual transformation of mental imagery in the reflective practice with the design interim products through the design process is proposed to capture the structure of reasoning. The identification of sketching episodes is determined by the 'transformation' or 'change of ideas' from one state to another.
- Sudden insights: The identification of creative qualities for the emergent actions is associated with the role they play in design reasoning. Two main categories are identified: 'preserving the flow' and 'defying the crowd'.

Chapter

5 Order, Structure and Disorder in Space Syntax and Linkography: Quantifying the Structure of Complex Graphs[43]

There has been great interest in the use of linkographs to describe the structure of events taking place in the design process with the aim of understanding the conditions under which creative moments emerge. Linkography is a directed graph to the time of emergence of actions and because of this it resembles the large complex graphs that are used in the space syntax community to describe urban systems. In this chapter, we investigate the applications of certain measures that come from space syntax analyses of urban graphs to look at linkography as well as strings of information measures. One hypothesis is that complexity is created in different scales in the graph from the local sub-graph to the whole. The proposed method of analysis illustrates the underlying state of any system. Integration, complexity and entropy values are measured at each individual node to arrive at a better understanding of the rules that frame the relationships between the parts and the whole.

A *linkography* is a representation of a series of events that can be observed to occur and can be used to help analyse processes of creativity during a design session. Linkography differs from spatial systems by having a time factor. A linkograph is constructed from nodes that represent each segment in the design process (according to time) and parses the dependency relationships between those nodes. Because it traces the associations of every move, the design process can be looked at as a linkography pattern that displays the structure of the design reasoning. Venues of dense interrelations (clusters of design utterances) are highlighted on the graph and can be further interpreted through the artefacts emerging throughout the process.

The linkography system is hypothesised to deliver different degrees of complexity on different occasions. The aim is to uncover the significant events that might be associated with creative insights and to inspect the artefacts that are formulated at such events. Linkography deals with multilevel complexities and the overall goal of the proposed analytical method is to reveal the relationship between the parts (sub-networks) of the system and the whole. The relationship between the sub-systems or partial assemblies is inspected from two perspectives, information theory and entropy theory, to see whether a conflict occurs between uncoordinated sub-orders despite the orderly structure (Arnheim, 1971; Laing, 1965) or whether an orderly system underlies a disordered state (Planck, 1969) – an entity that is dependent on a random dispersion of limited sub-orders (Arnheim, 1971; Kuntz, 1968). A computational method is proposed that covers the dependency relationships occurring between nodes, all of which appear to have a sophisticated group of relations. The algorithm used is inspired by the t-code string measure developed by Titchener (1998a, 1998b, 1998c, 2004).

5.1 A Point of Departure

A gridiron urban system is perceived as a highly organised structure if it enables navigation from one place to another. It is highly intelligible in this circumstance, but it may become confusing. In a very symmetrical system, the explorer has equal chances to move from one point in the system to another and might get lost. Since intelligibility is the correlation between connectivity and integration, the same correlation value is constituted for any element in this particular system.

In reality, no system is set up as a 100% symmetrical gridiron. Every city has some differentiation that adds to the structure and provides the capacity to grasp the relation between the 'whole' and the 'parts'. The example of two forests, *natural-spontaneous* and *farmed-grid*, reflects two different states. In the first, trees are not aligned and the distribution is chaotic, while in the second, trees are strictly planted along straight lines and the arrangement is similar everywhere in the network. In both

[43] Elements of this chapter were first presented by the author at the Eighth International Space Syntax Symposium at the Pontificia Universidad Católica de Chile, Santiago de Chile, 2012 (El-Khouly and Penn, 2012a).

cases, systems disorientate the explorer. Yet the highly ordered and the disordered forests are both considered extreme examples in terms of intelligibility (see Figure 5.1).

What deserves attention is how we construct a system for such a city. Hanson (1989) has pointed out that order might be misleading about its function and that it could be a manifestation of another underlying state. Hence, the importance of distinguishing this kind of relationship is crucial to reveal the real state at each stage of a multilevel complex system. Something might occur in the system somewhere between total chaos and total order, a certain point where it starts to behave differently from the preceding state(s). The demonstration of the gridiron order, despite being a singularity in intelligibility terms, is as unintelligible as the total chaos state. Both systems deliver lack of intelligibility for the thinking subject. Order, in this particular case, is just the same as complete disorder in delivering a lack of intelligibility. However, if we impose differentiation on the gridiron by adding some diagonals and routes, the whole structure has not drastically changed but its intelligibility moves from one state to another (the system becomes more intelligible).

Working with systems that have multilevel complexity on different scales is common in urban and linkography systems. One view is that there is a clear order and that the structure of the system can be easily grasped and understood. The other view is that there is no rule in the complex world and that it is actually just random. The paradox is that if it is truly random *is there a simple way to describe it? Can a complex world be reduced to a single value?*

This chapter proposes the hypothesis that in multilevel complex systems high orderliness tends to become less complex overall, and therefore a highly linked node delivers few choices and probabilities. The alternative to inspecting the system is therefore to measure the probability for each node and complexity at each level (at every sub-network) included within the system. In doing so, we propose the adoption of strings of information to code probabilities at each point and compute the information content from it. The practical aims of using this method are twofold:

- First, since all the inspected sub-networks have the same sub-graph size effect, the measures of strings at each point in the system are already relativised and eligible for comparison. This is because the information is extracted for all the possible relations that could be made from any point in the system to any other (the sub-graph size always equals n-1).
- Second, integration values are relativised to the sub-graph size. Thus, integration, complexity, rate and content of information are relativised parameters that we look at to specify the relation between the parts constituting the whole.

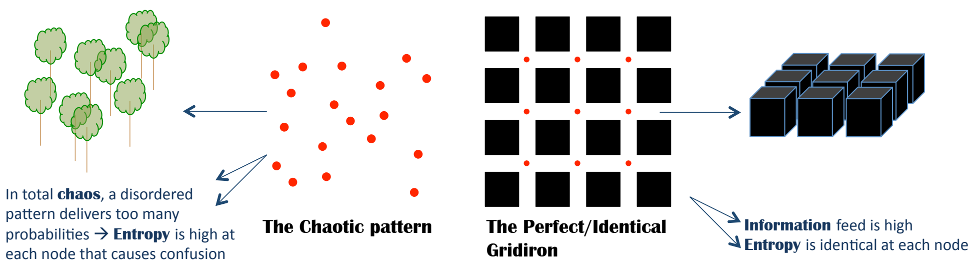


Figure 5.1 Two different structures of networks: disordered vs. ordered systems

5.2 Design Process as a Multilevel Complex System

This study begins by highlighting the characteristics of linkographs, which have been identified through analyses of different patterns and case studies and across various software applications. The following structure forms the hierarchy of linkograph: ‘nodes’ that aggregate forming ‘clusters’, ‘networks’ or ‘sub-system’ of relations. In some cases, networks (sub-graphs) do not intersect because the train of thought in this design venue is disconnected and the chunks of ideas are unrelated. However, in most cases, networks intersect in one or more nodes, which means that the design thoughts are structurally interrelated and built up.

Segregation or *integration* of networks varies from case to case: the pattern is sometimes coherent and parts are connected despite the diversity of the cognitive activities undertaken, but this cannot be postulated as a general rule because sometimes a total separation occurs between two or more subsets. Based on this, the structure of the linkograph varies between *fully connected and saturated* or *totally random and disordered*. Both are extreme situations in design thinking. Thus three prototypes of linkography patterns are categorised: *highly ordered*, *structured* and *disordered*, reflecting *integration*, *coherence* and *diversification* respectively. Figure 5.2 illustrates segregated versus integrated linkography patterns.

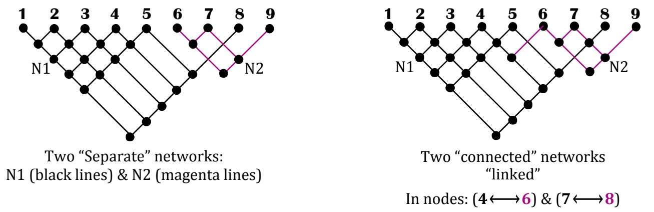


Figure 5.2 The relations between networks in a linkograph: separated or connected

The linkograph reflects a state of design that changes through time. This change might underlie an entire state with properties that cannot be identified through the outward appearance of the pattern. Schön (1983) suggests that a design transforms its state according to the change of repertoires in the mind. Our challenge is to understand how the transformation of ideas from one state to another can be captured. In addition, the *reflective practice* (a methodological design paradigm developed by Schön, 1983) plays a vital role in the manipulation process of the artefacts of design. Why do certain interim artefacts not reflect exactly what was happening in the designer's mind at a particular moment? Although the sketches result from the mind, there will be instances when the sketch will reflect back to some (buried) insight in the mind.

Goldschmidt (1991) revealed that a designer does not represent images held in the mind, as is often the case in sketching by non-designers, but creates *visual displays* that help induce images of the entity that is still being designed. This is considered an *intermediate* medium of representation to mediate between mental manifestations and design outcomes. Qin and Simon (1992) identified the role of mental representations and formation process in a study on understanding Einstein's 1905 paper on special relativity by using *mental imagery*. Subjects who translated text into images were able to manipulate, control, and observe these representations to run simple mental experiments. The mental representations and drawings appear to mediate between the initial natural language text and the final equations. In relating the cognitive processes with the linkograph, various patterns of mental representation can be inferred from studying the relations that can be made between the units of design. Figure 5.3 demonstrates how a linkograph can be configured from *ordered*, *structured* and *disordered* patterns.

A design situation includes different states that the designer works through but it is possible that one of the design states might become mechanistic leading to *idea stagnation*. An ethnographer observing a designer creating many alternatives might perceive the process as innovative, but this is not only the case. A pioneering designer can create a novel design concept with just a few lines and actions in a shorter time. Linking creativity to 'richness of ideas' or 'productivity' is still questionable. What deserves attention is how the design process is built up from the parts to the whole to look at the venues of high creativity within the structure. The proposition is therefore to investigate the synthesis of relations in every action and globally to understand the structure and describe the design process. In this context, it is vital to distinguish between information and entropy since most of the current publications on protocol analysis adopt entropy as a central element to describe the design process.

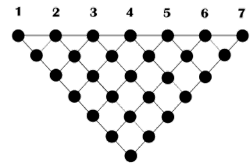
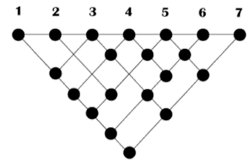
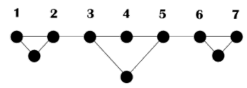
Pattern Type	Description of the State	*Linkography* Configuration
Order	▪ A highly ordered pattern states an ongoing identical probability to move from one episode to another ▪ It reflects a state that a designer keeps performing the same actions ever then ▪ A premature fixation effect of a certain idea may occur	
Structure	▪ A structured pattern delivers variable chances to develop an idea from one single utterance to another ▪ A diversification of various design ideas is experienced in the process	
Disorder	▪ A chaotic design situation reflects unrelated thoughts on the design situation ▪ It might cause total confusion and loss on the track of development	

Figure 5.3 Different states of design reflect different patterns

5.3 Information and Entropy

Space syntax and design process are multi-scaled complex contexts. The information content at different scales reflects the complexity at each level in the system. In the proposed method, the system can be read in two ways. The first looks at the probability of choice at any ‘item’, ‘point’, or ‘node’, while the second looks at the rate of information measured for a ‘sequence’ of items.

The methods correspond to entropy theory and information theory respectively. But while entropy is concerned with ‘sets’ of individual items, information is concerned with the individual ‘sequence’ of those items. The entropy theory asserts that a ‘set’ should be treated as a ‘microstate’; the microstates constitute the complexions of the overall process.[44] At this point, the main object of inquiry in information theory is to investigate the probability of occurrence by establishing the number of possible sequences. The ‘sequence’ of items is not covered in entropy theory but is necessary for information theory. Table 5.1 illustrates the differences between the two perspectives.

The term *entropy* was coined in 1865 by Rudolf Clausius (physicist), from the Greek words *en* and *trope* – mean ‘in’ and ‘turning’ respectively – in analogy with *energy*. The definition of entropy depends on its context, differing from *physics* and *thermodynamics* to *information* theory, and hence there is more than one definition to describe it. In physics, entropy is defined as the quantitative measure of the degree of disorder in a system. In thermodynamics, entropy is considered a measure of certain aspects of energy in relation to absolute temperature. It is one of various functions of state characterising the equilibrium of a physical system (how the substance reaches the equilibrium state).

In the present study, it is worth raising the point that the typologies of linkography patterns can be perceived from different angles, whether through *physics*, *information*, or *entropy* theories. The significance of the perceived patterns is differentiated according to the angle from which we look at it. In the following chapters, we will highlight whether a relation exists between the three configuration types of linkography patterns – whether *orderliness*, *disorderliness*, or *structured* – based on El-Khouly and Penn’s study (2012a).

Information and *entropy* are two viewpoints for looking at linkography. While the information theorist looks at the *probability* that can be created for a sequence of relations for a single *item*, the entropy theorist considers the *set* (which is made up of items) a microstate on its own for the system. The

[44] Arnheim (1971) described the microstate in the principle of entropy theory thus: ‘The particular character of any microstate does not matter; its structural uniqueness, orderliness or disorderliness does not count. What does matter is the totality of these innumerable complexions adding up to a global macrostate of the whole process. It is not concerned with the probability of succession in a series of items but with the overall distribution of kinds of items in a given arrangement.’

two theories are in opposition. Entropy grows with *probability*, while information increases with *improbability*. The less likely an event is to happen, the more information its occurrence provides.

Entropy is a measure of the state of disorder for any system. The aim of estimating entropy in information theory is to predict the probability of an event occurring. The objective of information theory is to investigate probability by establishing the number of possible sequences that can be created per single item. The sequence of an item is not taken into account in entropy theory but is necessary in information theory. Information theory is adopted to develop a quantitative approach to quantify the possible relations that are likely to occur at each item in the linkograph. Table 5.1 highlights the differences between information and entropy.

Table 5.1 The differences that distinguish *entropy* theory and *information* theory

	***Information* Theory**	***Entropy* Theory**
Structure	▪ Structure means nothing is better than those certain 'sequences' of items that can be expected to occur	▪ Items constitute the main characteristics of the structure
Principles	▪ Focused on the individual 'sequence' of items ▪ Is about 'sequences' and 'arrangements' of item	▪ Concerned with 'sets' of individual items ▪ Is about the 'overall distribution' of kinds of items in a given arrangement
	▪ The less predictable the sequence, the more information the sequence will yield, and the more remote its representation from order	▪ The more remote the arrangement of sets is from a random distribution, the lower its entropy, and the higher its order representation
Examples	▪ A highly randomised sequence will be said to carry 'much information' by the information theorist because information in this sense is concerned with the probability of this particular sequence	▪ A randomised distribution will be called by the entropy theorist 'highly probable' and therefore of low order because innumerable distributions of this kind can occur
Application	▪ For example, Titchener et al.'s (2005) computation of strings of information ▪ For example, Brettel's (2006) adoption of Titchener's (2004) t-code measures to estimate entropy for navigation routes	▪ For example, Kan and Gero's (2005a; 2007; 2008) estimation method to acquire entropy from linkography ▪ For example, Turner's (2007) adoption of Shannon's formula to estimate entropy for urban systems with *Depthmap*

An observer would find that the most highly ordered system provides maximum information content and thus is opposite to probabilistic entropy since the prediction is very high. If total disorder provides maximum information as well, then maximum order is conveyed by maximum disorder (Arnheim, 1971). However the distinction can be made through a parameter that measures the underlying system of any order. Since *information* is a crude measure that confirms a clear increase in regularity overall, extreme regularity and apparent similarity are likely to deliver a very low probability value.

Entropy grows with the probability of a state of affairs while information does the opposite and increases with the improbability. The less likely an event is to happen, the more information its occurrence represents. The least predictable sequence of events will carry the maximum information. Hence, this chapter focuses on how entropy could be estimated for multilevel systems in a way that views the relationship between the nature of complexion between the partial assemblies that are made at each point and the whole. The proposed method therefore adopts entropy and complexity as independent measures to assess complex systems such as linkography; see Figure 5.4 for a representation of sub-networks in linkography. However, it should be noted that the structure state of any system needs a variation of characteristics in order to construct an intelligible system.[45] The next section reviews methods to estimate entropy and introduces the computational method of strings of information.

[45] Referring back to the example of the gridiron system, all elements deliver the same correlation value between connectivity and integration; however, any imposed differentiation on the gridiron cause variations on intelligibility, and then system changes from one state to another.

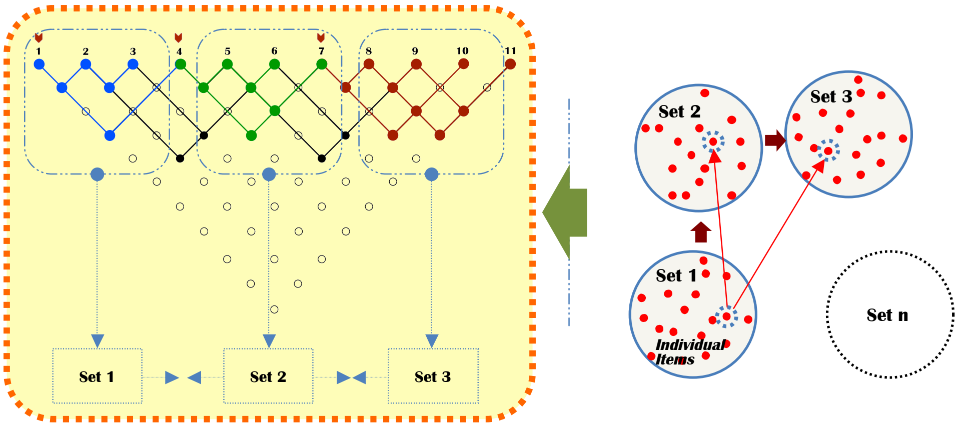


Figure 5.4 A hierarchical linkograph consists of nodes, clusters and sets (sub-networks) – sets might be *connected* or *segregated* (left). A complex system consists of multiple *sets* that are connected through individual *items* – nodes (right)

5.3.1 Entropy of Spatial Systems and Linkography

The estimation of entropy for spatial systems is based on the frequency distribution of the point depths (Turner, 2007). The point depth entropy of a location, s_i, is expressed by utilising Shannon's formula of uncertainty as shown in the equation:

***Point Depth Entropy* for spatial system →** $$s_i = \sum_{d=1}^{d_{max}} -Pd \log_2 Pd \qquad \ldots\ldots\ldots \quad \text{(I)}$$

Where d_{max} is the maximum depth from vertex v_i and P_d is the frequency of point depth d from the vertex

Estimating point depth entropy in this way shows how *orderly* a spatial system is structured from a certain location. The method is a functional equation based on 'mean depth'. In *Depthmap*, the information from a point is calculated with respect to the expected frequency of locations at each depth. Turner (2007) explained that the 'expected' frequency is based on the probability of events occurring depending on a single variable, the 'mean depth' of the j-graph. The benefit of calculating *entropy* or *information* from a 'point' in space syntax pertains to how easy it is to traverse to a certain depth within the system. Low disorder is easy; high disorder is hard.

In linkography (with reference to Gero et al., 2011; Kan and Gero, 2005b, 2005c, 2007, 2008, 2009a, 2011; Kan et al., 2006, 2007), Shannon's theory of information (1948) is adopted to inspect the occurrence of dependency relationships between moves.[46] This gives two possible choices to code the system: 'linked' and 'unlinked' (or 'on' and 'off'). The formula used is:

***Shannon Entropy* for Linkography →** $$H = -(p_{linked} . \log_2 p_{linked}) + (p_{unlinked} . \log_2 p_{unlinked}) \ldots\ldots \text{(II)}$$

5.3.2 Paradox of Shannon Entropy on *Balanced* Linkographs

Kan and Gero's method looks at the overall distribution of 'sets' (items of relations) regardless of the 'sequence' of occurrence of elements constituting the linkography according to time. The example in Figure 5.5 emphasises that the differences between two linkography patterns are not considered in the estimation process of entropy. This is owing to the summation step – processed over the whole network – for each of the two probabilities, 'linked' and 'unlinked', regardless of the position of items in the system that should precede the estimation.[47] Both graphs have the same entropy value despite the clear difference of arrangements in each system. This is because the equation is based on summing the values of each

[46] Goldschmidt (1992) defined a design 'move' or 'step' in the following terms: 'a move is an *act* of reasoning that presents a coherent proposition pertaining to an entity that is being designed'. Goldschmidt (1995) also stated: 'a *step*, an *act*, or an *operation*, which transforms the design situation relative to the state in which it was prior to that move' (see also: Goldschmidt, 1990.)

[47] Remember that linkography is a directed graph to the time of occurrence for each design 'utterance'.

probability without considering the position of each in the existing pattern. The next section provides a synopsis on intelligibility in space syntax. It illustrates a brief from a previous study (Brettel, 2006) that combined string measures with integration values on spatial networks with distinctive configurations, investigating the *connectivity* between nodes through *navigation* in various samples.

The applications of classical entropy to quantify entropy have been argued by Chou (2007) and Chou et al. (2013). Chou pointed at a *factor* that must be considered in order to rectify the estimation process of Shannon entropy. His method adjusts entropy value with a *pattern–matching* factor to pick up the frequency of appearance of patterns in the estimation. Chou argues that a frequent pattern implies a degree of responsive repetition that in consequence involves an aspect to decrease entropy value. The algorithm proposed by Chou and Chou et al. aims to determine the frequency of pattern occurrence but to this extent, the appearance of '*irregular*' patterns is still inaccurately measured in this attempt.

We argue that the application of Shannon entropy treats the linkograph in terms of *sets* and *networks* regardless of the sequential arrangement of occurrence of microelements that constitute the set according to *time* (the order of relations is according to the emergence of nodes). It looks rather at the overall distribution of sets in a global manner. Figure 5.5 shows an illustration of two different linkographs (design processes) where both contain the same number of nodes (same 'n' size of the system) but with different total distribution. Interestingly, both graphs sum up the same value of *linked* and *unlinked* relations giving an identical single entropy value when applying the equation:

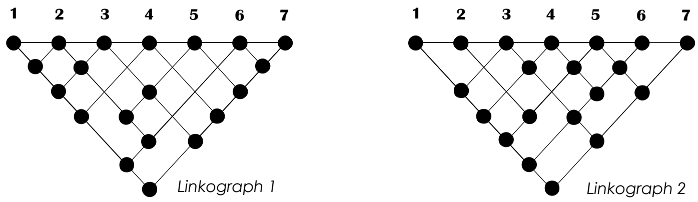


Figure 5.5 Two different linkographs give identical values of Shannon entropy

Processing Shannon Entropy (H) on two different linkographs:
$\mathbf{H = -(p_{linked} \cdot \log_2 p_{linked}) + (p_{unlinked} \cdot \log_2 p_{unlinked})}$
The total number of possible relationships = n[(n-1)/2] = 7(6/2) = 21
Where n is the total size of the linkography (the number of nodes)
The total number of 'linked' relations in both graphs is = 13 → ≃ 61.9%
The total number of 'unlinked' relations in both graphs is = 8 → ≃ 38.1%
$\mathbf{H} = -[(13/21) \times (\log_2(13/21)] + [(8/21)\times(\log_2(8/21)]$
$\mathbf{H} = -[(0.62) \times (-0.69)] + [0.38] \times (-1.39)]$
$\mathbf{H} = -0.4 \times 0.5 = \mathbf{0.2}$ **bit/bits**

Since linkographs with different arrangements of relations reflect different design processes, classical application of entropy is merely associated with the quantity of links regardless of the variation in distribution. The paradox still exists in this sense if we refer entropy into a single node/design move. The question is: *can we reduce a multilevel complex system of the whole design process into a single entropy value*? This in fact points to the importance of creating a *dynamic* measure[48] to evaluate each 'step' and design 'move' occurring in the design process.

5.4 Quantifying the Linkograph via T-code Sets of Information

El-Khouly and Penn (2012a) introduced the computational method of strings on information to linkography. In this method, '*linked*' and '*unlinked*' relations are coded into binary codes of '1' and '0' respectively. The string can be extracted for each move in the graph; whether strings of backlinks, forelinks, or concatenated strings, all can be processed implementing the *wtcalc* tool. *Wtcalc* and *ftd* tools are part of the '*deterministic information theory*' (DIT) development.[49] Titchener (1998a; 1998b; 1998c; 2004) proposed this theory with an aim of evaluating the flow of bits produced from a source of

[48] The term '*dynamic*' entropy is introduced in Kan and Gero (2009a).

[49] See Appendix 5.1 for a comparison between *wtcalc* and *ftd* computational methods and their effects on the precision of results.

information. The theory passed through different stages of development. This chapter presents a synopsis of the most important characteristics and applications of the DIT theory and introduces a *computational* tool to quantify the linkograph.[50]

For a linkograph with a total number of (i) vertices, a string of codes is formed for node (i) with i-1 bits such that bit j in that string is '0' if there is no backlink from node (i) to node (j) and '1' if there is such a backlink. Moves that have few potential 'partners' to link with (i.e. nodes with low (i) in the case of backlink consideration and nodes with high (i) in the case of forelinks) give a low T-complexity. Two methods are proposed: one operates on the level of individual nodes; the other subdivides the graph into subsets or sub-linkographs.

5.4.1 Method 1: Processing T-codes for individual moves

Our prime target is to compute *t-complexity* and *t-entropy* at each node in the linkograph, where both measures fluctuate throughout. In this method, the process to compute extracted strings can be carried out via one of three ways, which differ according to the direction of reading links (backward or forward):

- **Extracting *Backlinks* String per Each Node**

In this method, all relations are extracted in a reverse way to the emergence (from end to start). For a linkograph with a maximum size of five nodes: node 5 has relations (*linked* or *unlinked*) with 4, 3, 2 and 1, while node 1 has no back relation since it is the starting point.

In extracting *forelink* strings per each node, all relations are extracted in a forward way, like the direction of growth in the linkograph (from start to end). For example: node 1 has forward relations (*linked* or *unlinked*) with 2, 3, 4, 5, … n, but node n has no forward relations since it is the end point. Foreword and reverse methods are both *synchronous* to the emergence of links. Figures 5.6 and 5.7 illustrate an application of 'reverse' or 'forward' methods of processing strings on a linkograph where the direction of reading makes a significant difference to the final results.

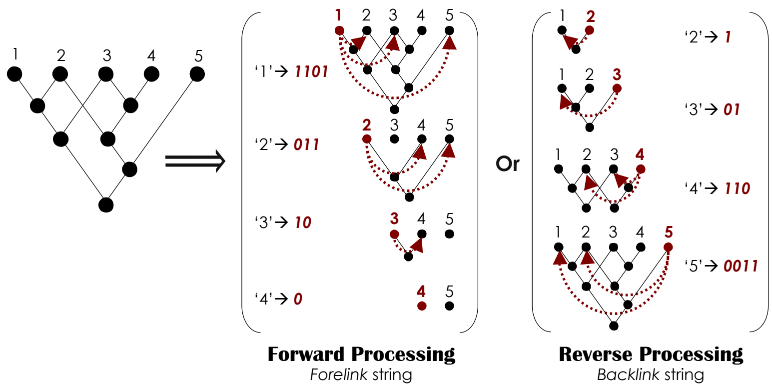


Figure 5.6 An application of extracting the strings: forward or reverse

For example, in a linkograph with 5 nodes, if strings are extracted in reverse, node '1' has no preceding relations, '2' might have a relation with '1', '3' has two probabilities with '2' and '1', '5' has four with all the preceding nodes. Generally the string out of 'n' has (n-1) string size, but in forward processing, the string out of '1' will have four probabilities while the last point '5' will have no probabilities with any following nodes.

[50] Refer to Appendix 5.1 for an introduction for the theory and other methods to quantify the linkograph Goldschmidt (1990) and (Kan and Gero, 2005a, 2005b, 2005c). Evaluation of the quantitative measures are discussed in light of the comparison between Shannon entropy and deterministic information measures.

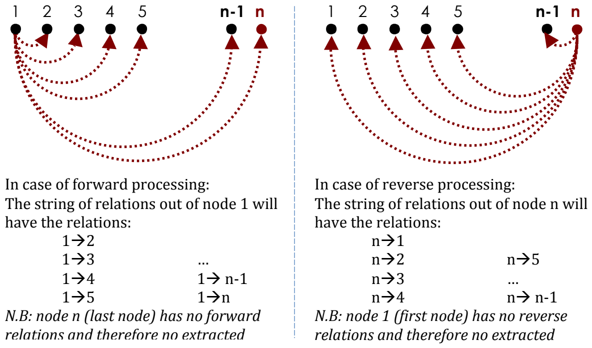


Figure 5.7 Extracting the string in two directions: forward or reverse

- **Concatenating *Backlinks* and *Forelinks* Together per Each Node**

This is a third method based on concatenating both strings (*backlinks* and *forelinks*) per each node together in order to process one longer string at once. Many methods can be suggested to extract a character string of information. The proposed method for a linkograph is to undertake the *synchronous* occurrence of nodes and to consider the direction of reading the relations. Figures 5.8 and 5.9 illustrate the extraction of one concatenated string for each node in the linkograph by composing one string for the *backlinks* and *forelinks* relations.

In this hypothetical graph, node (15) has the following coded relations: *Backlink* string is **01111011011111** and *Forelink* string is **101110** and the concatenation is **01111011011111.101110**. Figures 5.8 and 5.9 presents insight on the concatenation of links from node 15 to the others.[51]

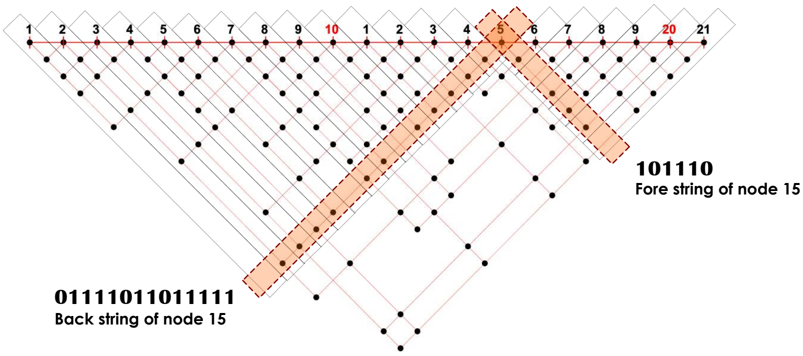


Figure 5.8 Extraction of concatenated string of the *back* and *forelinks* for node 15 (the highly connected)

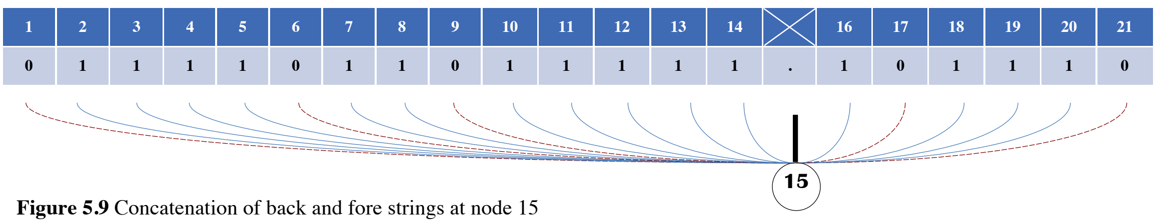


Figure 5.9 Concatenation of back and fore strings at node 15

Either method is feasible; computing the t-entropy individually for each string or concatenating the strings and computing it once. As a general rule, complexity and entropy measure tend to 'converge' as strings get longer, but the effect would be seen mostly with much longer strings than the ones we are looking at here (hundreds if not thousands of bits). If there were no particular reason for keeping them separate, we would rather concatenate. If we intend to eventually concatenate strings for all points, some

[51] This method was first presented by the author at the Eighth International Space Syntax Symposium, 2012 (El-Khouly and Penn, 2012a). It was then referenced (with Figures 5.8 and 5.9) in Goldschmidt (2014).

redundancy may be introduced because each point's *backlink* is another point's *forelink*, and so forth until the end of the process.

5.4.2 Method 2: Processing T-codes for Subsets or Sub-linkographs

In this method, the linkograph is subdivided into a series of subgraphs (see Figure 5.10). The subdivision can be made in two ways: *time rate* or *amount of nodes*. In each, *back* and *fore* strings can be computed similarly to method 1 (*individual* or *concatenation*). However, it should be noted that measures per frame must be normalised to the n-size of the sub-system in order to 'relativise' the results of the subgraphs together.

Relativisation is necessary to achieve the required accuracy but the result is conditional on being divided by the logarithm of 'the n – total number of nodes in each subset – ($\log_2 n$).' The calculation process starts by setting up the number of nodes (or occurrence rate) in a hypothetical window that slides across the baseline of the linkograph. The more a window displaces, the more nodes are included in the estimation process.[52]

This method is built on the basis of two factors – *time* and *activity* – that must be described in the design process. We can inspect a certain activity that is relevant to time of emergence, e.g. by looking at a certain sketch (design medium) that has specific start and end points. The emergence of action and the formation of concept are illuminated to find which actions are pivotally responsible for the emergence of a novel idea. The application of t-codes to linkography is looked at in a design case study.

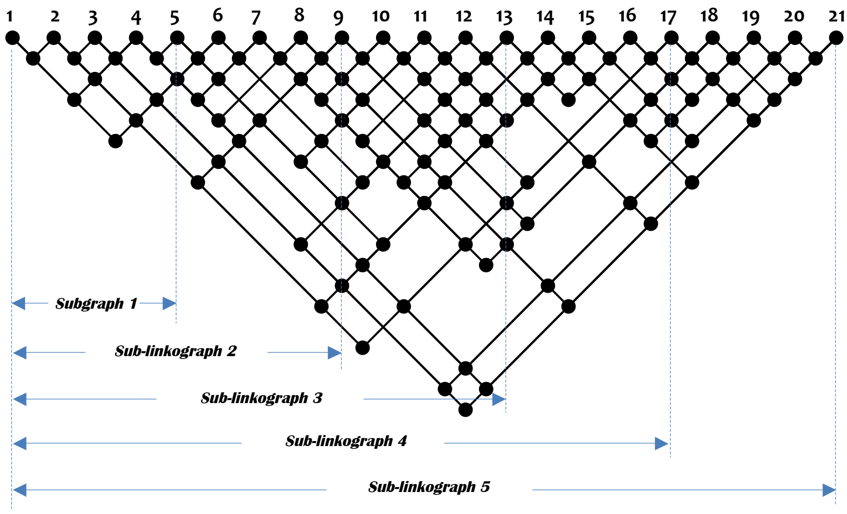


Figure 5.10 Processing the linkograph as a series of subgraphs

5.4.3 Introducing *Redundancy* to the Computation Process of Concatenated Strings of Information

Each point's *backlink* is another point's *forelink*, so some redundancy can be introduced in this way to increase the precision of measures of computational process. Looking at the sample linkograph, node 15, for example, has a forelink to point 18, among others. Say we were to construct a string by concatenation as follows:

> **[*forelinks* of point 1][*backlinks* of point 2][*forelinks* of point 2][*backlinks* of point 3][*forelinks* of point 3] … [*forelinks* of point n]**, where **[(fore|back)links of point n]** is the bit string we already described.[53]

---

[52] Refer to Appendix 5.1; *Relativisation* is introduced to the computation method.

[53] To invoke the *ftd* algorithm, asking about the practicality of encoding and using ftd. We would suggest using a scripting language (e.g. PHP) to encode the linkograph and prepare the strings, and then use the language's shell extension (e.g., backticks in PHP) to invoke ftd, e.g., like so:

```
$string = '1010101011110101101101 1010'; // prepare string
$result = `/path/to/ftd -mb $string`;
```

However, in order to achieve redundancy[54] and accurate results, instead of recording the existence of a link between 15 and 18 twice; once as part of (forelinks of point 15) and once as part of (backlinks of 18), our linkograph can be described in its entirety in this way just by recording the *forelinks* only (or the *backlinks* only) of each point. Thus, having each link recorded twice is redundant.

5.5 How a Complex System is Viewed

Support for the hypothesis may be found in Brettel's (2006) study, which investigated how 'order', 'structure', and 'disorder' of street layouts are perceived when navigating through an urban environment. In this study, Brettel states 'An ordered environment tends to be more intelligible when broken up by an irregularity occasionally.' In our study, we ask: *Under which circumstances does the system change from one state to another?* But more specifically on Brettel, we enquire: *Are highly intelligible spatial systems predictable to navigate through*? And, *Does simple traverse through urban fabric deliver less complex structure*?[55]

String of information measurements to deal with 'event' structure were introduced in Brettel's study[56] in order to compute barcodes of event sequences extracted from navigation routes, in addition to syntactical analysis. The string measures were expected to relate to the perceived order along a route. The entropy of each route's string was interpreted as the probability of the uncertainty that a route provides for the traveller, and was expected to relate to the perceived structure along routes.[57] When a route has very few turns, the probability of choices is too low (e.g. gridiron patterns such as New York and San Francisco).

However, entropy delivers high values (relatively) with complex patterns when the route consists of some turns and deviations within it (e.g. composite fabrics of urban structures such as London and Rome). Moreover, the isovist fields owed the differentiation of visual catchment areas between the analysed cities not only according to the 'delineation' in the route but also because of picking up structurally different catchment areas, especially in the irregular patterns. Figure 5.11 illustrates the application of the string of information method on the circulation routes of two different cities (Brettel, 2006).

According to Brettel's analyses, the computation process of strings could deliver meaningful correlations for the perceived route. Nevertheless, the assumption that *orderliness* is likely to be more related to *complexity* measure and *structure* to *entropy* could not be proven in her study, possibly due to limits of the survey setup.[58] So are we measuring '*intelligibility*' *versus* '*complexity*' or '*integration*' *versus* '*complexity*'?

The central point of attention is to realise that intelligibility is a system property; the correlation between *connectivity* (C) and *integration* (I). Complexity (C_T) of graphs is also a system property that reflects how many steps are required to construct a string of information for the system (or sub-system). Consequently, values of the two parameters can be compared and correlated together. The sub-graph at each node is also a sub-system and the same measures can be used to inspect the characteristic within the whole.

There are a variety of means to illustrate a network; see Figure 5.12 for some examples. The scope of this study is not concerned with multiple representations to illustrate the system, but rather

For running a sliding window, PHP has arrays, loops, and string processing functions –so we can essentially do what we want. The advantage of this is that there is no need to recompile.

[54] Redundancy means to avoid computing the link between any two nodes twice. Some say the link between two nodes has two-way direction, but we claim that by introducing 'redundancy', we can achieve accurate results for the overall network. In this sense, 'redundancy' leads to 'accuracy'.

[55] In other words, if the mechanism of access from one point to another is simple, does the synthesis form of its route deliver low complexity?

[56] An 'event' is defined as a segment of time at a given location that is perceived by an observer to have a beginning and an end (Tversky and Zacks, 2001).

[57] The probability of choices that could be made at decision points for directional turns. Accordingly, entropy describes how much information is there in a 'signal' or 'event'.

[58] This result may be limited owing to the small size of samples and short strings.

intends to understand the constituting force that attunes the components of it (such as what is beyond the links and relations between the nodes). Before embarking on an analysis of the distribution of integration in each of the individual nodes in the system, we begin with a number of common features of the set of linkographs, which give some idea of the nature of the processes envisaged.

After a preliminary study on some samples of linkography, the concluded points are twofold. First, since the total number of links in any system of size n is (n-1), then the size of any node's possible relations equals (n-1) as well. This means that at any node, the sheer number of links in the sub-graph created from this node to the others in the system has the same size effect with every node. Accordingly, all the measures are relativised at every level in the system before embarking on comparisons. A second feature that differentiates between systems is the varied distribution of links. This should be considered in the estimation process of strings of information to include the sequences of sets in our interpretation rather than viewing the system at the node level only.

Example: Application on Urban Environments

Brettel (2006) developed a model computing strings of information for the characteristics of navigation through urban environments based on a transcription of the events structure.

Event structure → 'Turns' and 'Changes of direction'

Occurrence – no distance measures accounted

How information is assembled from "situation-based" experience (such as transitional views and non-static views) in travelling –based on abstract overview knowledge– that can referred to new situations of spatial experience?

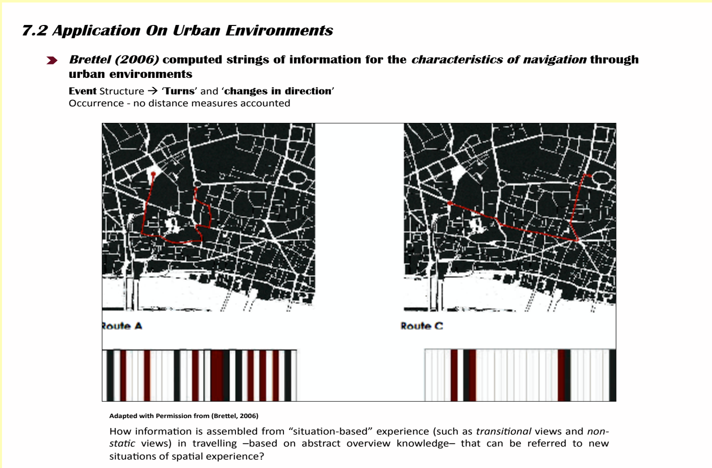


Figure 5.11 Illustration of applying the string of information method on the circulation routes of two different cities
Source: Maps and barcodes are adapted from Brettel, 2006, with kind permission of the author.

Three levels can be identified representing a hierarchical complex system: the 'overall', 'sets of items' and the 'individual items', using 'top-down' hierarchy. A system can then be viewed from two different angles:

1) Relationships between the *sets*, forming the overall complex macroscopic structure (see Figure 5.13).
2) Relationships between the *individual items* of different sets forming the microscopic level (see Figure 5.14).

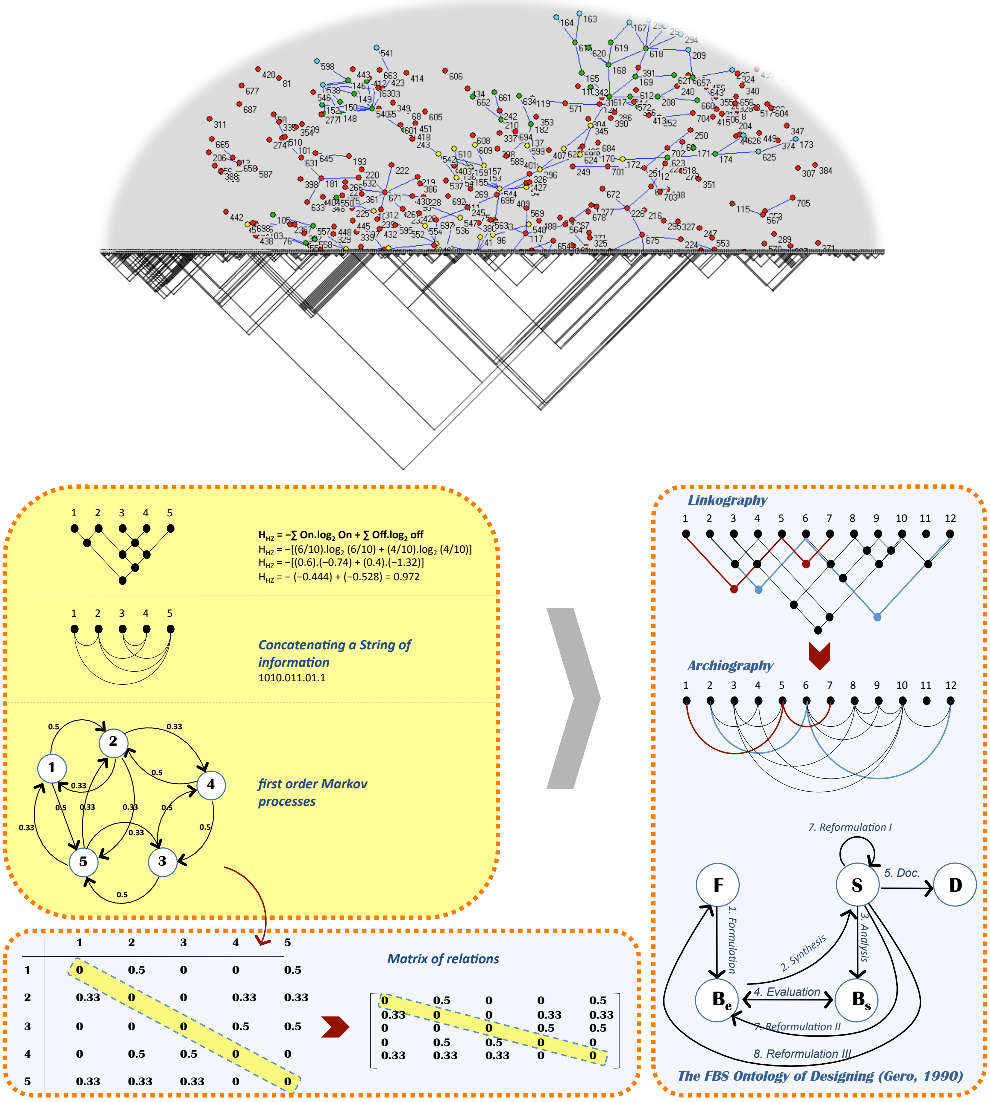


Figure 5.12 Representing linkographs via various forms: archiograph, Markov chain, or distributed network

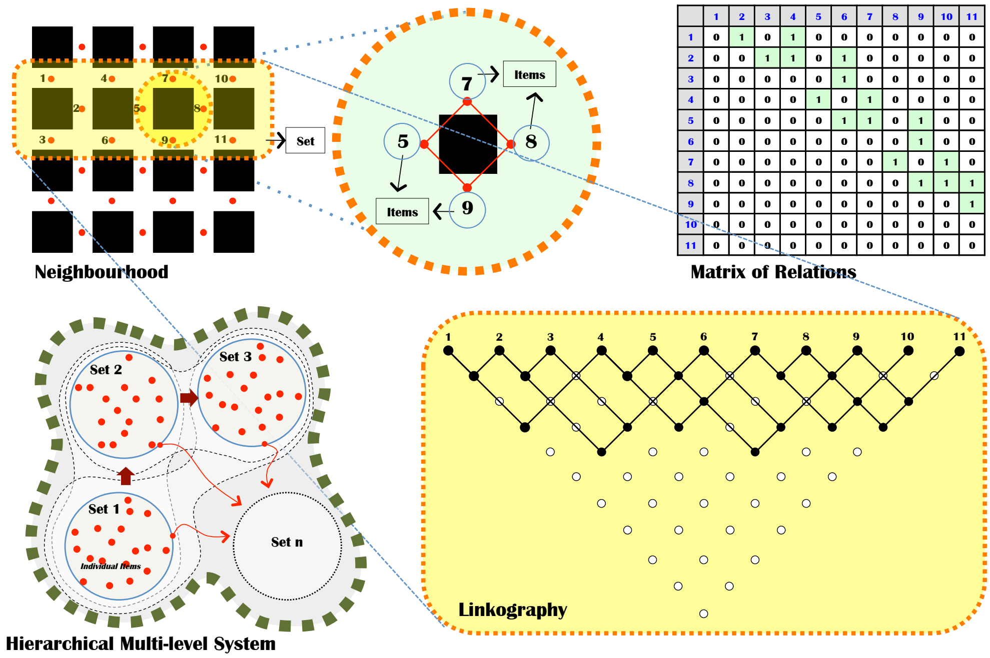


Figure 5.13 Relations between sets form the primary (macroscopic) level of structure

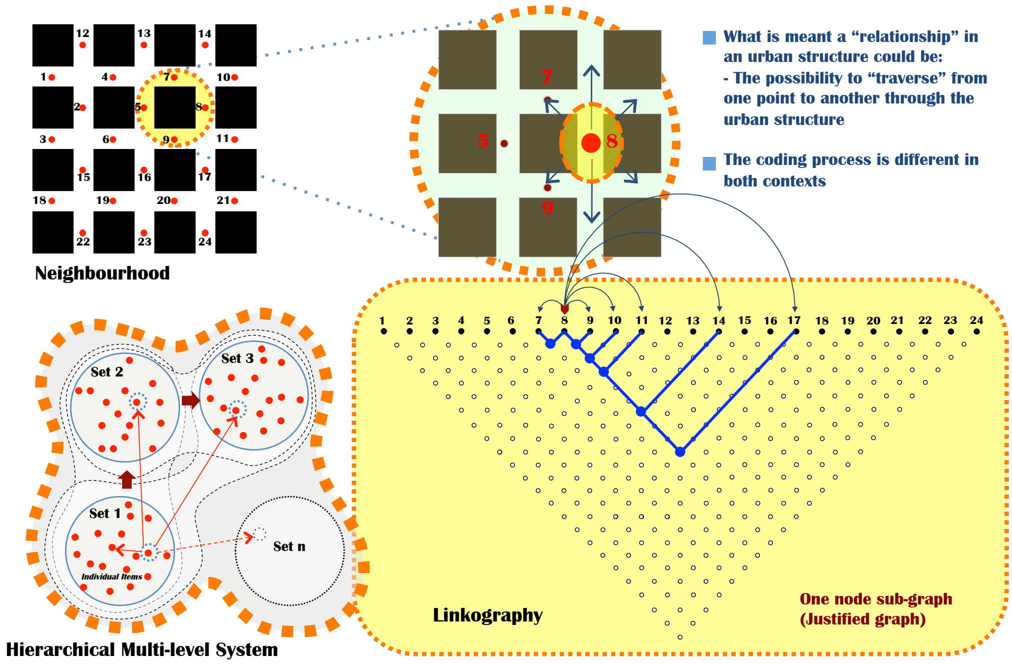


Figure 5.14 Relations between individual items form the primary (microscopic) level of structure

5.6 Intelligibility, Complexity and Entropy

There are a variety of syntactic measures that can be implemented to quantify the structure of multilevel complex networks, such as *linkographs*. *Connectivity* measure is the number of immediate vertices that are directly connected to the present vertex under the quantification test, providing a local static measure. *Depth* measure is the least number of syntactic steps in a graph that are needed to reach one vertex from another. It is the natural metric distance between all pairs of nodes. *Integration* is a static global measure that describes the average depth of the network created for the vertex to all other vertices in the system. The vertices of a system can be ranked from the most integrated to the most segregated.

> Depth is the mean path length L_i from a vertex. It is the average number of edge steps to reach any other vertex in the graph using the shortest number of steps possible in each case (Hillier and Hanson, 1984).

A shallow network means the vertex that this network is created for is directly connected to the other vertices in the network. Depth measure is very low and integration is very high in this case. Depth and integration are inversely correlated. However, a deep network reflects low connectivity between the vertex and the other vertices in the network that requires multiple steps to reach from one side of the network to this vertex. The more steps required, the higher the depth measure. Integration is very low in this case.[59] Figures 5.15a and 5.15b illustrate both examples.

- High integration means that the system established at this vertex is shallow, although the vertex is highly connected. It means that the mean depth and relative asymmetry of this node is low. High integration is related to how the node is integrated within the system according to the normalised value of mean depth. We must then distinguish between connectivity and integration. It is incorrect to correlate connectivity and integration since both represent different characteristics in the structure of networks.
- Low integration means that the mean depth and relative asymmetry of this node is high; many steps are required to reach the end of the system. Having the lowest degree of integration in the whole system reflects a deep system that is an 'unlinear' sequence of relations (steps) to reach the other edge vertex in the graph (system) using the shortest number of steps possible.

Integration = 1/Real Relative Asymmetry (RRA)

[59] See Chapter 8 for more on the syntactic measures for justified graphs and directed linkographs.

A dilemma occurs when a vertex that has the least connections/links in the whole graph delivers the 'highest' integration value. To explain the dilemma: *relative asymmetry* (RA), or *relative depth* can be thought of as the measure of integration. The least depth exists when all vertices are directly connected to the original vertex and the most depth is when all vertices are arranged in *unlinear* sequence away from the original vertex as every additional vertex in the system adds one more level of depth (see Hillier and Hanson, 1984). As a rule of thumb:

- Low value of mean depth (MD) indicates a vertex from which the system is 'shallow', i.e. a space that tends to 'integrate' the system; see Figure 5.15a.
- A high value of relative asymmetry and mean depth indicates a vertex from which the system is 'deep', i.e. a space that tends to be 'segregated' from the system; see Figure 5.15b.
- Mean relative asymmetry is a general measure of integration for the system as a whole. Note that integration is inversely correlated with real asymmetry and mean depth.
- *Closeness centrality* is a measure of how long it will take to spread information from a vertex to all other nodes sequentially. It is considered the inverse of the farness depth; the more central a node is, the lower its total distance (depth) from all other nodes. It is 'inversely' correlated with both mean depth and relative asymmetry – resemblance of the integration measure.
- *Betweenness centrality* quantifies the number of times a node acts as a 'bridge' along the shortest path between two other nodes. It indicates the control of a human on the communication between other humans in a social network (Freeman, 1977). Vertices that are predicted to occur on a randomly chosen shortest path between two randomly chosen vertices have a high betweenness. Betweenness centrality correlates with mean depth – resemblance of relative asymmetry.

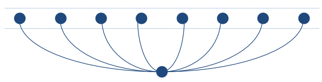


Figure 5.15a Illustration of a shallow system that delivers high integration value, very low MD and RRA values

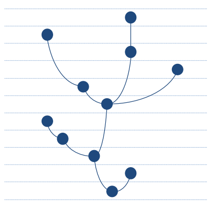
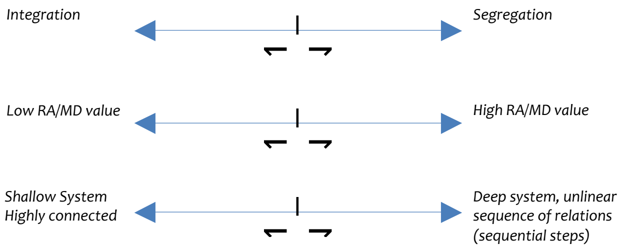


Figure 5.15b Illustration of a deep system that delivers low integration value, high MD and RRA values



Intelligibility and complexity are properties of multilevel systems. For a graph that consists of 100 nodes, each node will have two values: (1) intelligibility, which is the correlation between two values: connectivity and integration; and (2) complexity, which is measured for the 'sub-graph' of relations at this particular node. Both measures have 'size' effects. For intelligibility, where a system size is 'n' (n<50) intelligibility will tend to be high (for example, a small village with 50 links, paths or axes gives the range of values 0<0.5<1.0).

The system is ‘intelligible’ if the correlation value is more than 0.5, and ‘unintelligible’ if the value is less than 0.5. String measures such as complexity, information content and entropy also have ‘size’ effects. For a string of size ‘n’, (n<20), values are ‘inaccurate’. Accuracy for information and entropy is limited for short strings due to the approximation of the bound by the logarithmic integral function (see Titchener, 2004). For a string of (n>20), the t-complexity we are looking at is a ‘sub-graph’ of the whole linkography, namely those nodes that are directly connected to the node we are estimating. Subsequently, the t-complexity and t-entropy measures are comparable to the integration value at that same node. Hence, the highly connected nodes at any system could be correlated to the string measures at the same node in order to investigate the proposed hypothesis. According to Brettel (2006), that intelligibility is signified throughout orderly systems.

As a rule of a thumb, the shortest line between two points is a straight line that has a first order synthesis form. A piazza is highly accessible from all its surrounding points (areas), the proposed path of navigation is clear and easier to travel, and thus the expectation is high and the complexity is low. A cul-de-sac has a very low integration value in the system and not many options exist to approach it – only one access point. That makes it very complex to reach.

Giving an example of a particular spatial structure, Figure 5.16 illustrates two hypothetical network systems that are connected via only one node (resembling a bridge between two riverbanks); the real relative asymmetry (RRA) value of this single node equals zero. Since integration and RRA are inversely correlated, this means that the most integrated point in the system is the highly linked node. Other nodes in each side are equivalent in integration and RRA values. This network will still be represented in several ways. It may be deduced that both network sides are highly ordered. However the string of information for each node in the system contains repeated symbols that indicate only one possible option (symbol) of interconnectivity inside each side. This will significantly affect the computed barcode measures for each node in the system.

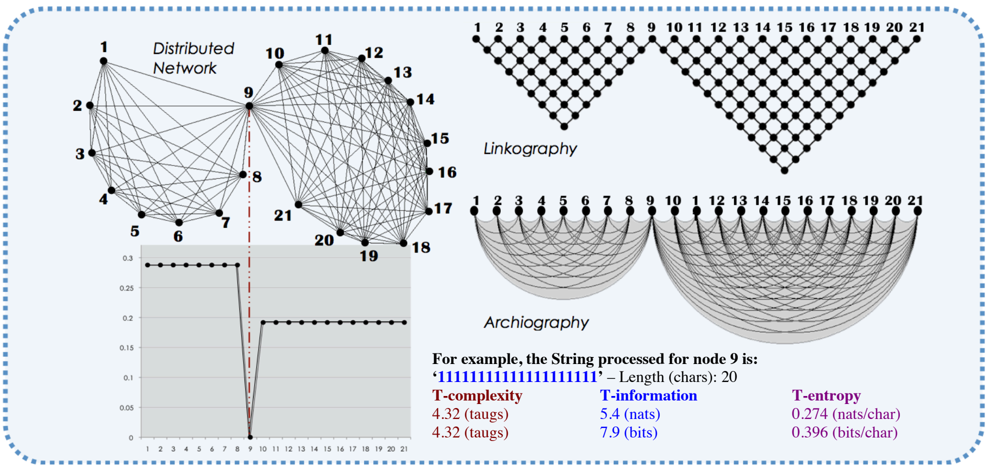
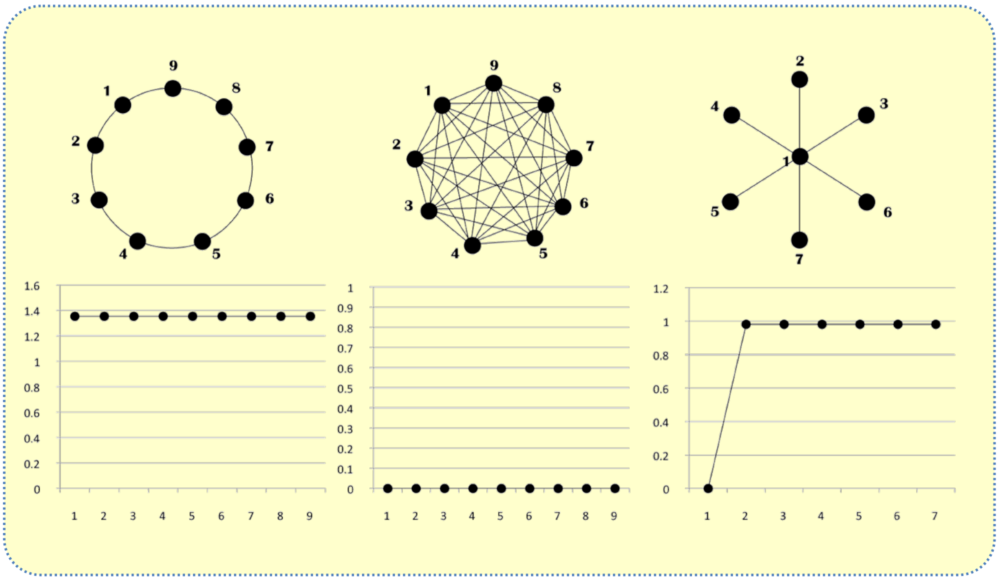


Figure 5.16 RRA values for a hypothetical network (connected only through a single node)

5.7 Applications: Examples and Cases

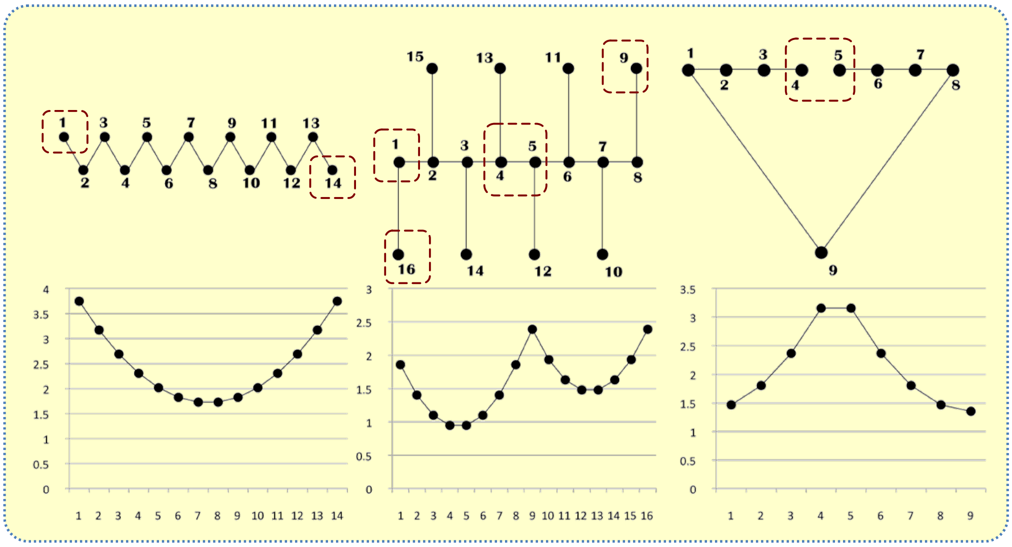
5.7.1 Hypothetical Cases of Short Strings

The following hypothetical cases are generated to inspect the relation between highly connected nodes and the t-complexity and t-entropy measures. The patterns vary between orderliness and structured configurations (see Figures 5.17 and 5.18). The RRA value is utilised to search for the most integrated node(s) in each pattern and process the comparison with the string measures.



Circular Boundary System	**Fully Linked Saturated Sys.**	**Radial/Polar System**
▪ Each node has two links only; with the preceding and the following ▪ RRA values are identical for all nodes ▪ The “overall” entropy of the system equals 1, which is the maximum value in case of applying Shannon’s theory. This means two choice are equally probable, “link” or ‘no link”	▪ Every node is connected with all the others in the system ▪ RRA values are equal and all equals zero since the system is fully saturated and symmetrical ▪ All the nodes deliver low entropy value since there is only one probability of choice in the system (all are “linked”)	▪ The central node is strongly connected to others on the periphery ▪ The peripheral nodes have one link only with the central one ▪ RRA values are equal for all nodes except the central one that delivers zero RRA due to its high integration within the system ▪ Entropy at central node 1 is low since only one choice is possible to go anywhere within the system
Example: Node: 9 **String processed: 10000001** **Length** (chars): 8 **t-complexity ǀ t-information ǀ t-entropy** 3.81 (taugs) 4.5 (nats) 0.5 (nats/char) — 6.6 (bits) 0.8 (bits/char)	**Example: Node: 1** **String processed: 11111** **Length** (chars): 5 **t-complexity ǀ t-information ǀ t-entropy** 2.32 (taugs) 2.4 (nats) 0.4 (nats/char) — 3.5 (bits) 0.7 (bits/char)	**Example: Node: 1** **String processed: 111111** **Length** (chars): 6 **t-complexity ǀ t-information ǀ t-entropy** 2.58 (taugs) 2.8 (nats) 0.4 (nats/char) 2.58 (taugs) 4.0 (bits) 0.6 (bits/char)

Figure 5.17 Values of RRA and string of information for hypothetical cases of radial systems



Saw-Tooth Sequential System	Doubly-Loaded Staggered Sys	Incomplete Disconnected Sys
▪ RRA values vary along the system and take the form of "catenary" parabolic chain ▪ The more points towards the centre (intermediary nodes), the less RRA value. This means integration increases whenever the nodes are set in the middle of the network	▪ A linear route with four prongs branching out in both sides and staggered. This configuration has three levels of connections: nodes with solo link only, nodes with two links, and nodes with triple links ▪ Given the RRA values, the lowest values are delivered by the intermediary nodes with more links (4 & 5), and the highest are delivered by the outer-edge nodes (1,8,9,16)	▪ This system represents a disconnected urban fabric where a move through a full loop is necessary to access the other side ▪ RRA values vary, the highest measures are delivered by the far-side nodes (on both edges)
Example: Node: 8 **String processed: 0000001100000** **Length** (chars): 13 **t-complexity I t-information I t-entropy** 4.95(taugs) 6.65(nats) 0.45(nats/char) 4.95(taugs) 9.65(bits) 0.7(bits/char)	**Example: Node: 4** **String processed:** **0010100000001000** **Length** (chars): 16 **t-complexity I t-information I t-entropy** 5.38(taugs) 7.57(nats) 0.47(nats/char) 5.38(taugs) 10.92(bits) 0.68(bits/char)	**Example: Node: 1** **String processed:** **10000001** **Length** (chars): 8 **t-complexity I t-information I t-entropy** 3.81 (taugs) 4.5 (nats) 0.5 (nats/char) — 6.6 (bits) 0.8 (bits/char)

Figure 5.18 Values of RRA and string of information for hypothetical cases of linear systems

According to the results of short strings, the following points can be concluded at this preliminary stage:

1. The high certainty of prediction in some networks might deliver only one choice (100% choice); thus entropy equals zero if applying Shannon's equation, and t-entropy decreases if applying t-code algorithms.
2. First, the total number of relations in any system of size 'n' is n(n-1)/2. However, the size of any sub-graph string equals (n-1) (see Appendix 5.1).
3. Despite the differences between the RRA values in any system, it might happen that all nodes have the same string measures since all have the same percentage choices (number of links).

4. The fall of t-complexity and t-entropy indices with the rise of RRA in the cases looked at misleads our hypothesis and causes disruption to the correlation values. The reason for this is the lack of accuracy experienced with short strings of information (less than 20 codes).
5. Either Shannon entropy or the 'deterministic' entropy is 'inversely' proportional with RRA, but since integration equals (1/RRA), the question arises of whether this confusion comes about because of inaccurate computation of short strings, or might there be another parameter that has its effect on both measures?

The application of t-complexity and t-entropy is tricky in this sense. Two points can be made from our experience of processing the computation method: (1) The position of nodes within the system determines the synthesis (structure of symbols) of the extracted string since the connections (links) that could be made from a certain node to the other(s) are based on the choices of routes/links. (2) Since each node's 'forelink' is another point's 'backlink' within the system, then an introduction of some 'redundancy' in this way should be considered in the estimation process to avoid replication (in case of concatenating the overall strings into one for the whole system). To reconcile these findings, another series of long string cases are analysed in the next section. But first we provide a definition of information and a summary of the assumption and aim:

Information is a crude measure that confirms a clear increase in regularity overall, extreme regularity and apparent similarity are likely to deliver a very low probability value.

Assumption: The 'information content' at different scales reflects multilevel complexity.

> An observer would find the most highly ordered system provides maximum information content and is opposite to probabilistic entropy. If total disorder also provides maximum information, then a maximum order is said to be conveyed by maximum disorder state (Arnheim, 1971.)

Aim: To find a protocol to highlight the underlying states of any system.

Target: How to estimate 'entropy' or 'information content' in a multilevel system, in a way that distinguishes the natural complexion of partial assemblies at each node/point.

5.7.2 Hypothetical Cases on Large Systems

The case studies are extended to include the analyses of eight examples of longer length linkography samples in order to further test the hypothesis and to overcome the inaccuracy experienced with short strings. These hypothetical systems are divided into two categories: '*modular order*' and '*structural*', where the former is known by its *repetitive rhythmic* patterns and the latter is distinguished by its *variation of choices*. Syntactical and string measurements are applied to study the degree of correlation between integration and 'dynamic t-complexity' and 'dynamic t-entropy'.[60] (See Figures 5.19 and 5.20; see also Table 5.4 at the end of this chapter for full measurements for each hypothetical case).

The quantitative method has been tested on many standard samples of the study; first, on a variety of modular ordered linkographs and, second, through a variety of structured networks. The first group of highly ordered configured linkographs states an ongoing identical probability to move from one designing episode to another, reflecting a state where a designer keeps performing the same actions providing a kind of repetitive rhythmic process that could reach a state of saturation. A premature fixation effect of a certain idea may occur with high probability on this occasion. The second group of samples delivers variable chances to develop the design idea, from one single utterance to another. It is distinguished by the diversification of various ideas that are experienced in the design process.[61]

[60] The term *dynamic* entropy, introduced by Gero et al. (2011) to indicate that each node in the system has its own entropic measure and therefore the values fluctuate along the linkography. See also: Kan and Gero (2011).
[61] Refer to Figure 5.3 to get more insight on types of linkography configurations.

- **Modular Ordered Linkography Patterns**

The following samples show highly ordered saturated patterns with different states of design processes. Processing the string of information measures and depth/integration syntactical measures shows the following results (referring to Figure 5.19 of ordered linkographs):

1) *Bridging* nodes deliver high integration values in highly ordered networks. This can be seen and illuminated clearly in all the provided cases. Being fully linked constitutes the shallow state of node with very low mean depth and real relative asymmetry RRA values.
2) The repeating pattern character codes of the string of information measure extracted for the bridging nodes comprises low complexity and entropy measures. This can be observed via both proposed methods for obtaining strings of information measures upon linkography patterns; for concatenated as well as backlink computational methods.
3) In the fully linked mode, integration (depth measure) and strings of information (for the sequential barcode relations) can be correlated since the network is highly saturated, giving a shallow system that is singularly layered (not multilevel with complex structure). This can be obviously observed in case 1.

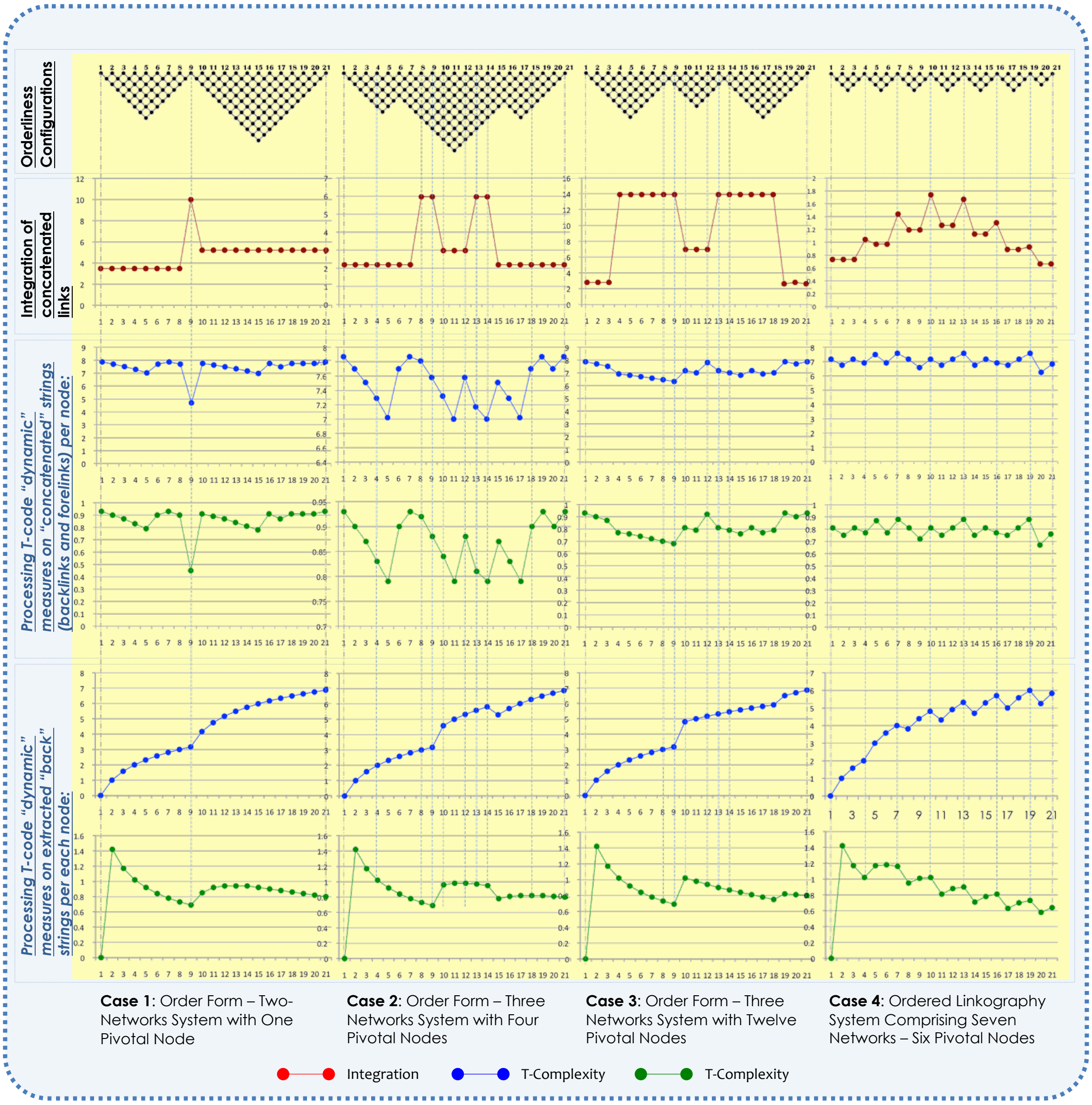


Figure 5.19 Highly ordered linkographs – hypothetical cases showing the relationship between syntactical integration (depth measure) and strings of information measures for the configuration of order state

- **Structured Linkography Patterns**

In the structured linkographs four different types are experimented and quantified via the proposed method. The patterns range from an inclination to evacuation state where most relations are unlinked to the state where most relations are linked but with diversification. This variation of graphs tends to deliver a spectrum of results with the aim of deriving a more precise conclusion on the characteristic of structured linkographs. According to the illustration for syntactical integration in Figure 5.20, the following results of Figure 5.20 are deduced:

1) The relation between *connectivity* and *integration* measure is not directly associated or correlated. Integration is about the depth of node in the network and is categorised in two main states; one where the node is deeply structured within the network and another where it is directly shallowly linked to the other vertices in the whole network. The transformation of integration measure in the four structured cases make the rule: high integration value represents the shallow mode of structured nodes, while low integration constitutes deeply synthesised networks. This rule accords with *bridging* nodes in the linkograph; which can be varied via similar taxonomy to *shallow* versus *deep* structures.
2) The more diverse the pattern of character codes composing the string of information, the higher t-complexity and t-entropy measures delivered.

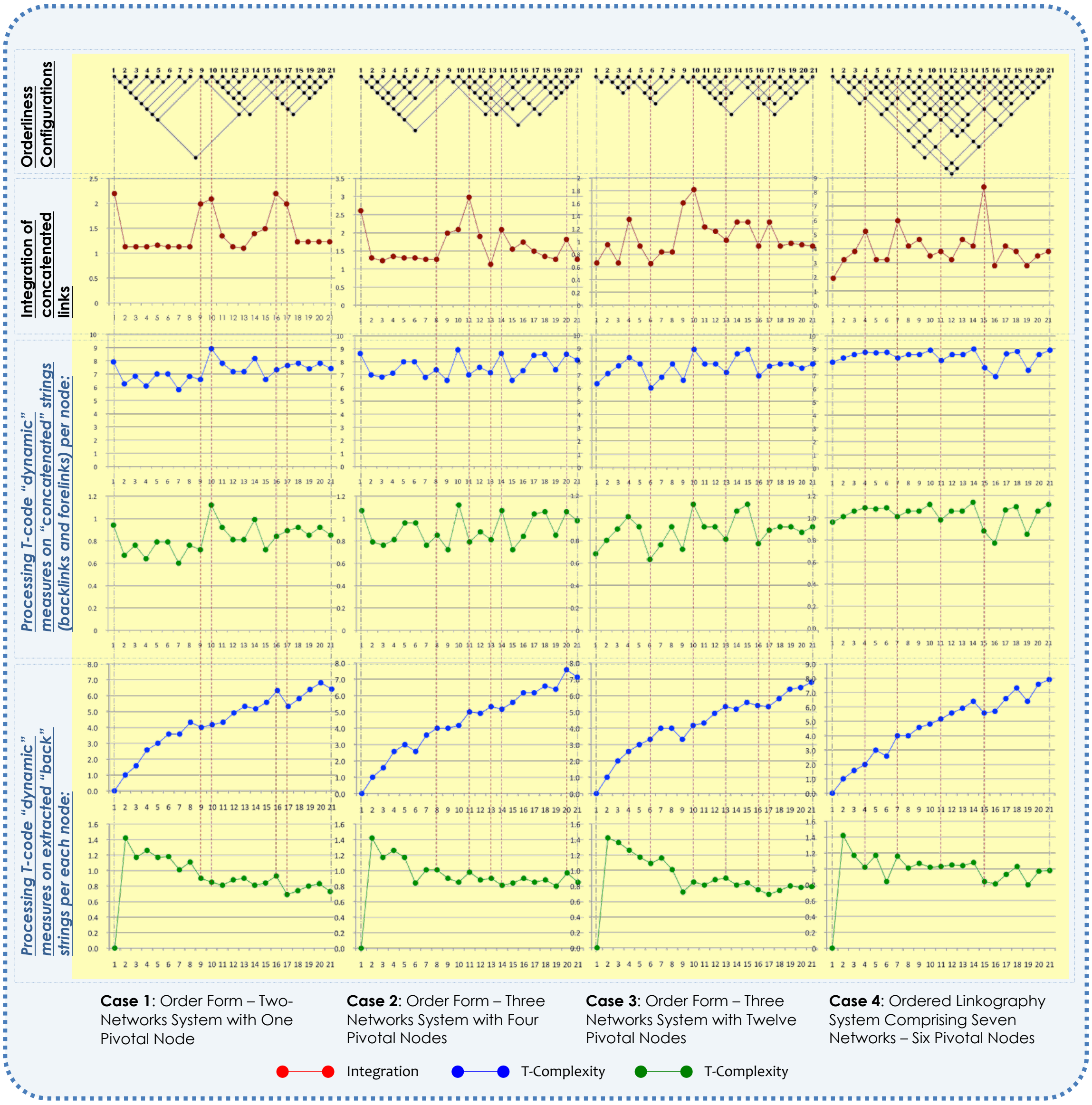


Figure 5.20 Structured linkographs – hypothetical cases showing the relationship between syntactical integration (depth measure) and strings of information measures for the configuration of structured state

From the *modular ordered* and *structured* linkographs and ethnographic observations of several design cases, the following conclusions on the interim study are deduced:

1) *Bridging* nodes illustrate sudden paradigm shifts in the design process; shifting from one structure state of a certain concept to a different one.
2) *Integration* and strings of information measures are 'non-correlated' due to the type of each measure. Syntactical integration is '*depth-based*' while the t-code sets compute the sequential relations of finite codes. The former measure counts for the multilevel complexity of the graph while the latter looks at the '*direct*' relations only. Both measures can be correlated in the exceptional case of fully linked saturated network where the nodes are very shallowly structured in the network. However, this is still a matter of investigation in the following analysis.

According to Figure 5.21 (drawn from the results of Table 5.2), no meaningful correlation between integration and t-complexity and t-entropy can be proved in all the ordered cases. However, in case 4 of fully-linked system, integration and t-complexity correlation is 0.39. This means that: *The shallower the system the higher the degree of correlation between integration and t-complexity*.

However, in the structured cases (see Figure 5.20) only one case delivers a high correlation between integration and t-complexity, reaching 0.55 in case 3. This lack of evidence is due to the low degree of diversification in the structure of the system (the pattern is shallow), which was not the case in the other patterns. Thus, we conclude that t-complexity and t-entropy are not correlated along ordered and structured networks.

It is apparent that some correlation values are negative: 'negative correlation' means that in a relationship between two variables, both variables cannot be correlated constituting totally different independent entities. A perfect negative correlation means that the relationship that appears to exist between two variables is highly negative (perhaps reaching -1).[62] Nevertheless, the inverse correlation between t-complexity and t-entropy brings out another point to test. It is hypothesised that the more complex a string (the variety of symbols), the higher the probability of uncertainty, the higher the correlation between t-complexity and t-entropy values.

Table 5.2 Values of correlation for the hypothetical systems

Variables of Correlation	Modular Order Systems				Structured Systems			
	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Integration : t-complexity	-0.76	-0.22	-0.86	0.39	0.44	0.21	0.55	-0.01
Integration : t-entropy	0.17	-0.13	0.022	-0.04	-0.21	-0.24	-0.28	0.09
T-complexity : t-entropy	0.25	0.07	0.01	0.20	0.25	0.07	0.24	0.18

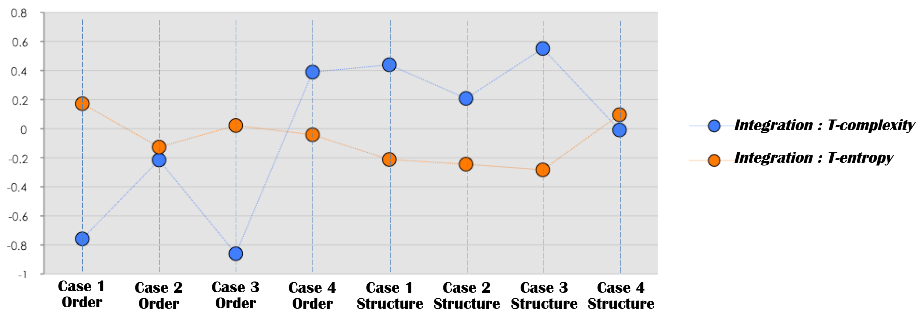


Figure 5.21 The correlation values of 'integration: t-complexity'; 'integration: t-entropy'

[62] A correlation in which large values of one variable are associated with small values of the other; the correlation coefficient is between 0 and -1. It is also possible that two variables may be negatively correlated in some, but not all, cases. A perfect negative correlation is represented by the value '-1', while a '0' indicates no correlation and a '+1' indicates a perfect positive correlation. This definition is retrieved from:
http://www.investopedia.com/terms/n/negative-correlation.asp#ixzz1ceYmvKXE.

However, the values of t-complexity and t-entropy converge with large systems (long strings) rather than the lack of accuracy observed processing *ftd* or *wtcalc* for short strings (see Appendix 5.1 for more detail on this). In short, after discussing this foundational study for our investigation, we enquire: *would entropy increase with higher complexity measures? How would the hypothesis of converse correlation with integration be affected? What does this means in terms of the structure of reasoning?*

5.8 Quantitative Method: The Correlation between Information String Measures and Syntactical Analysis to Inspect the Hierarchical Structure of Large Linkography Networks in Architecture Design Case Studies

5.8.1 Introduction to the Experimental Case Studies

A *descriptive analytical* approach through various samples of case studies is put forward to test the method from different perspectives to reach a reliable verification in various states of design processes. Since there are multiple factors that are involved in the design process (e.g. designing modes and settings using several tools and media application) aggregating the variables involved in the elaboration of methodological experiments undermines the *logic-deductive* approach of absence/appearance controlled variable tests. We prefer to adopt an *inductive* approach, reaching a conclusion based on the collection of data of many design samples, coding, grouping, categorising concepts (properties), hypothesis testing and validation.

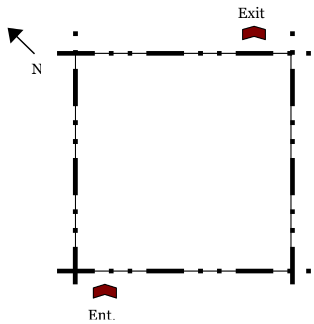
Two different experimental cases of architectural design (ranging in functional requirements, degree of constraints and specifications) were conducted on two architects (with more than ten years' experience), one to design an *expo pavilion* (Case Study 1) and another to design a *cheese factory* using conventional design tools (e.g. freehand sketching, *Sketchup*, and CAD application) (Case Study 2). The briefings in the design cases represent different states of structure and specification. The expo pavilion is specified with few functional and drawings requirements, while the cheese factory tends to constrain the designer with unfamiliar unknown type of functional requirements (i.e. *steriliser*, *pasteurisation* and *production line*). Figures 5.22 and 5.23 show illustrations for both design briefs.

Design Task: A Pavilion for Expo 2010, Shanghai:

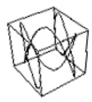
<u>Briefing:</u>

Dynamicity considers a vital aspect for the design of pavilion galleries. It could be achieved and reflected through circulations, zones, sources of light, and so on. The design problem always turns around the usability of a space, where *people* shape spaces.

You are requested to design a pavilion of arts expresses your country in the next expo2010, Shanghai, determined inside a peripheral of a cube (12x12x12) m^3. This pavilion must contain a gallery to exhibit portraits in addition to any subsidiary functions you find it relevant. Design the interior partitions that provide one way circulation and divide gallery to variant spaces.



<u>You are constrained to the following points:</u>



- 1st. To respect the marked entrance and exit in the figure above.
- 2nd. A one way circulation affair with a maximum length of 6 meters per each passage and 1.2m width.
- 3rd. Constructability consideration.
- 4th. Indirect natural lighting.
- 5th. To respect the prevailing wind while designing the external openings/shutters.

Time allowed is 1/2 hour where you are required to estimate the time in order to frame the design problem, form a concept, and generate a solution.

<u>Drawings required:</u>

- Plan.
- 3D-model/perspective.

For more information about expo2010, please visit: http://en.expo2010.cn/

<u>New Request:</u>

Dear Architect,

On behalf of the client, you are requested to include an open court (patio) in your design. This is to extend the pavilion to include 'outdoors exhibition' ***or*** *'open terrace' for visitors.*

You are given an indicated proposal (below) to place the patio within the given dimensions and orientation, however you are free to make another suggestion and reasonably amend the design. It might help to split the open terrace for the visitors somewhere else in the site. Specify your reasons in any case. Probably you might divide the outdoor exhibition to two, one in the patio and another outside.

Please make any changes you find to the circulation passages, functional areas around, indirect lighting & shading devices, and the exhibits.

Present your drawings to give a better understanding on your proposed concept in the time remains.

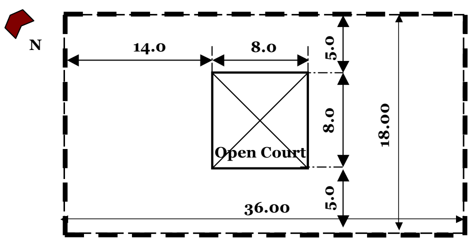


Figure 5.22 The design brief for the expo pavilion and the imposed request (Case Study 1)

Scenario:
You are requested to design a *cheese factory* proposed by the outlined rectangular area on the provided site. The design should be built on 50% of this footprint. The remained area is for vehicle manoeuvring and parking. Two loading docks on two different sides must serve this factory; one is used for feeding-in row material and another to load products out to the market. Each dock should include two vehicles clearance area.

The required functions are:
1. Refrigerator storages for row material and another for products.
2. Main industry hall on 50% of built area, consists of:
   a) Processing line: steriliser and multifunctional tubular pasteurizer for milk, yoghurt and cheese.
   b) Packing line.
3. Administration offices.
4. HVAC control room.
5. Rest room and WCs.
6. Parking area for six cars.

Instructions for the main hall:
1. The main hall should remain sterile (purified) without permitting open air.
2. An innovative construction concept for an open-plan space with fewer posts as possible.
3. Accessibility to controlled indirect lighting.
4. Maximum height to exceed is 12 meters.

Time allowed is 1.0 hour.

Drawings required:
- Plan.
- Section
- 3D-model/perspective.

New Request:

Dear Architect,
On behalf of the client, you are requested to include a showroom attached to the factory. This is to provide customers with information on the products and to setup marketing plans with clients.
This show room must include lounges and offices to discuss selling plans with dealers in addition to a meeting room for the staff. It could be a space whether vertically or horizontally separated from the factory. The gross area remains the same however and the added showroom must be included within 40% of the building's foot print area without reducing the main functional programme percentages (highlighted in the original design brief).
You are given an indicated proposal (below) to place the showroom within the given dimensions and orientation, however you are free to make another suggestion and reasonably amend the design. It might help to split the extension and visitors circulation somewhere else apart the master plan. Specify your reasons in any case.
Probably you might divide the building's height to few levels more.
Please make any changes you find to the circulation routes, functional areas around, entrances, lobbies and parking ... etc.
Present your drawings to give a better understanding on your proposed concept in the time remains.

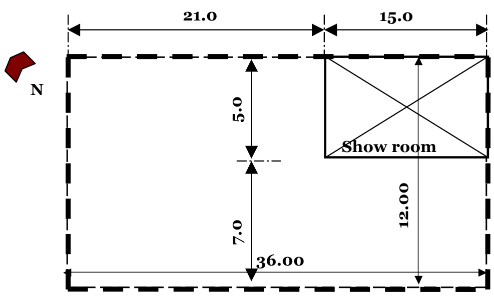


Figure 5.23 The design brief for the cheese factory and imposed request (Case Study 2)

5.8.2 Quantitative Analysis

In this study, we look at each design action (step) occurring by processing the linkograph using the introduced quantitative measures. The results are correlated with the qualitative judgment of the emerging products. We aim to assess the transformation of ideas and to capture any drastic (unexpected) change in the design reasoning process.

In this sense, the design process for each architect is decomposed into sketching episodes and preliminary units and coded judging the dependency relationships between the interim artefacts[63] and via multiple switches, back and fore linking between media sketches. Design actions are normalised against syntactic depth *integration*, string of information measures, and network analysis centrality measures of betweenness and closeness. Figures 5.24, 5.25a, 5.25b, 5.26, 5.27a and 5.27b illustrate the representation of the quantitative method on Case Studies 1 and 2.

- **Case Study 1: Expo Pavilion**

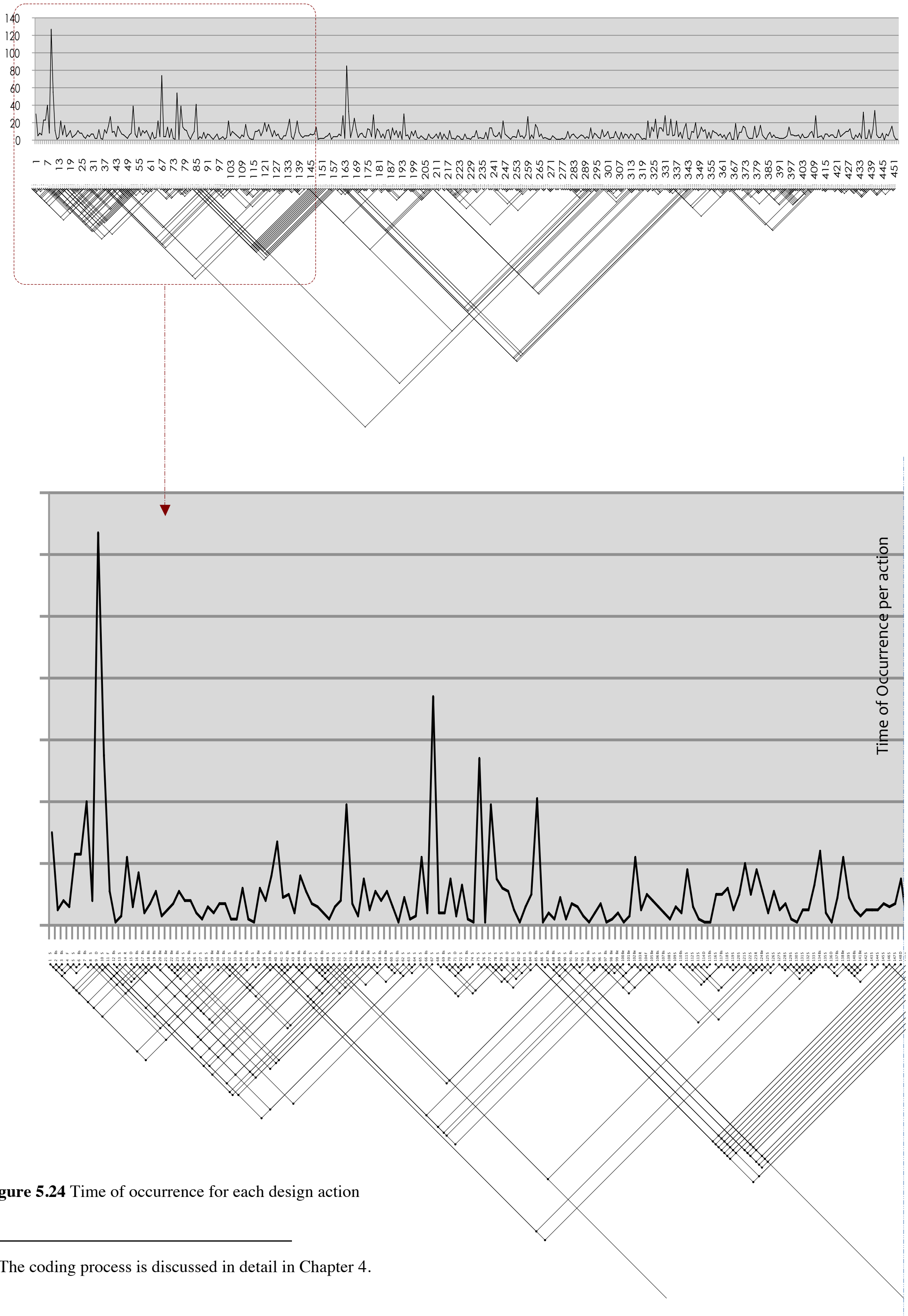


Figure 5.24 Time of occurrence for each design action

[63] The coding process is discussed in detail in Chapter 4.

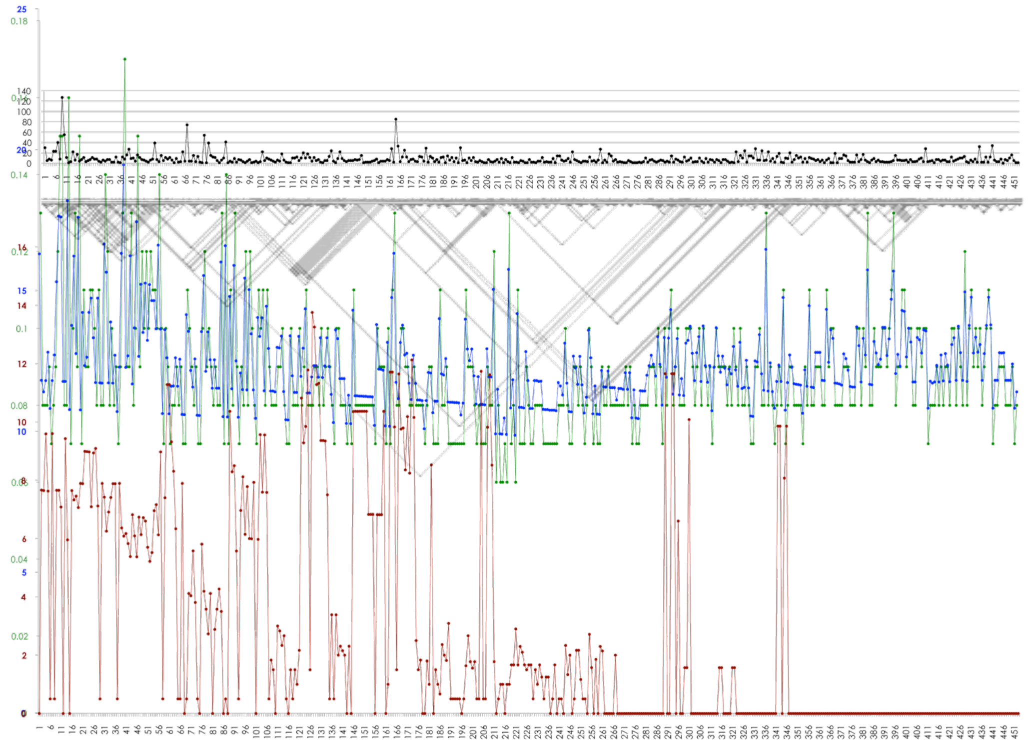


Figure 5.25a Strings of information measures; t-complexity, t-entropy for each design action

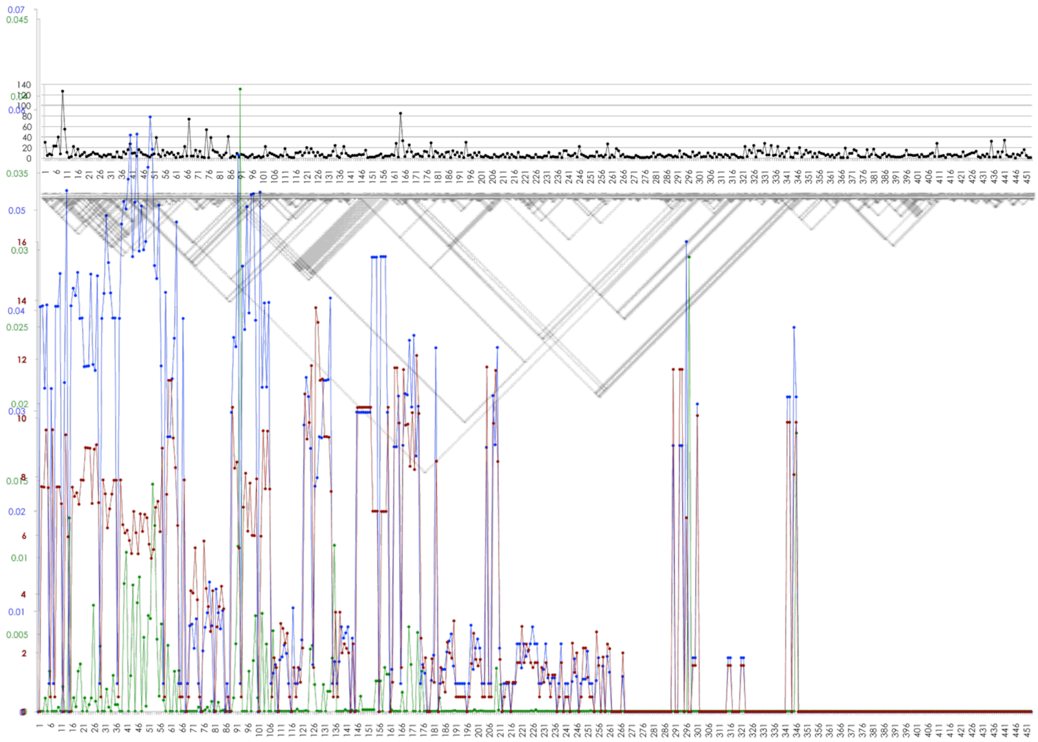


Figure 5.25b Syntactic and network analysis measures; integration, closeness centrality and betweenness for each design action

- **Case Study 2: Cheese Factory**

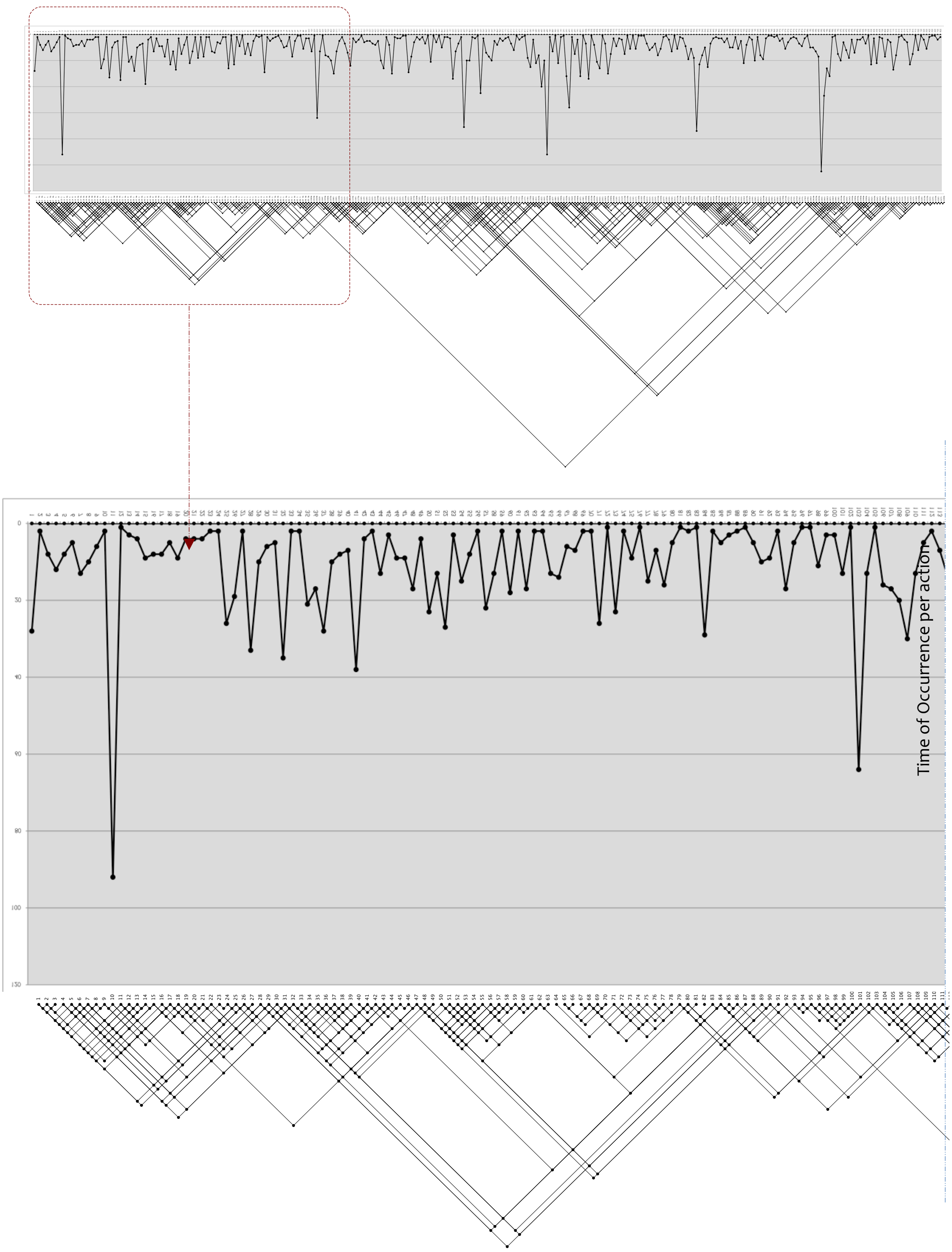


Figure 5.26 Time of occurrence for each design action

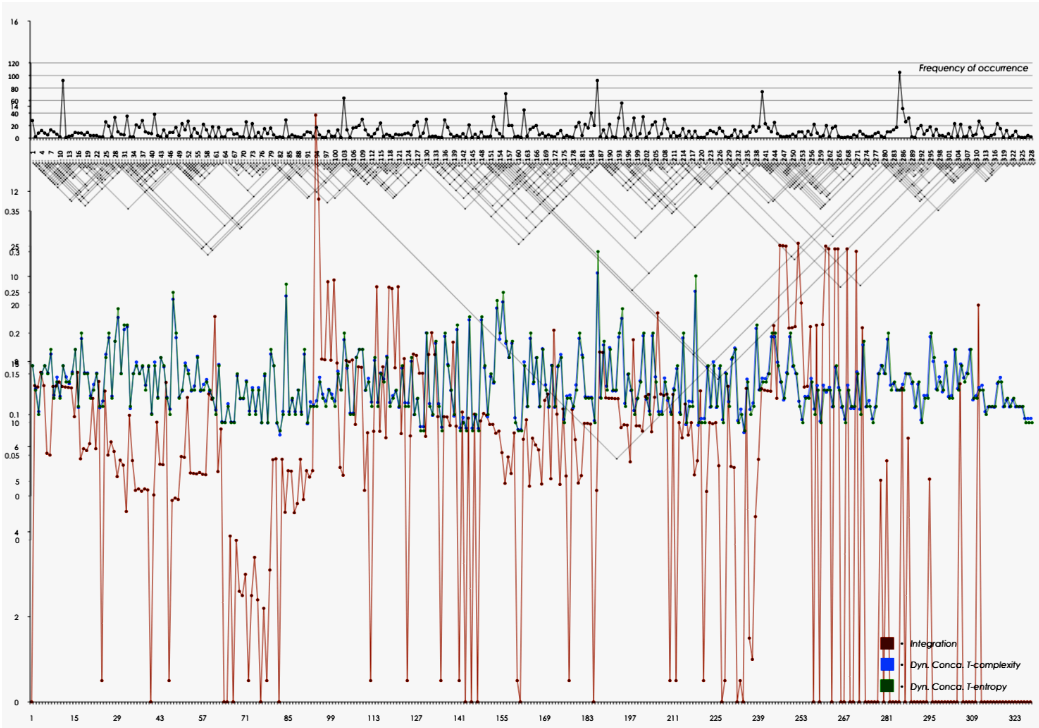


Figure 5.27a Strings of information measures; t-complexity, t-entropy for each design action

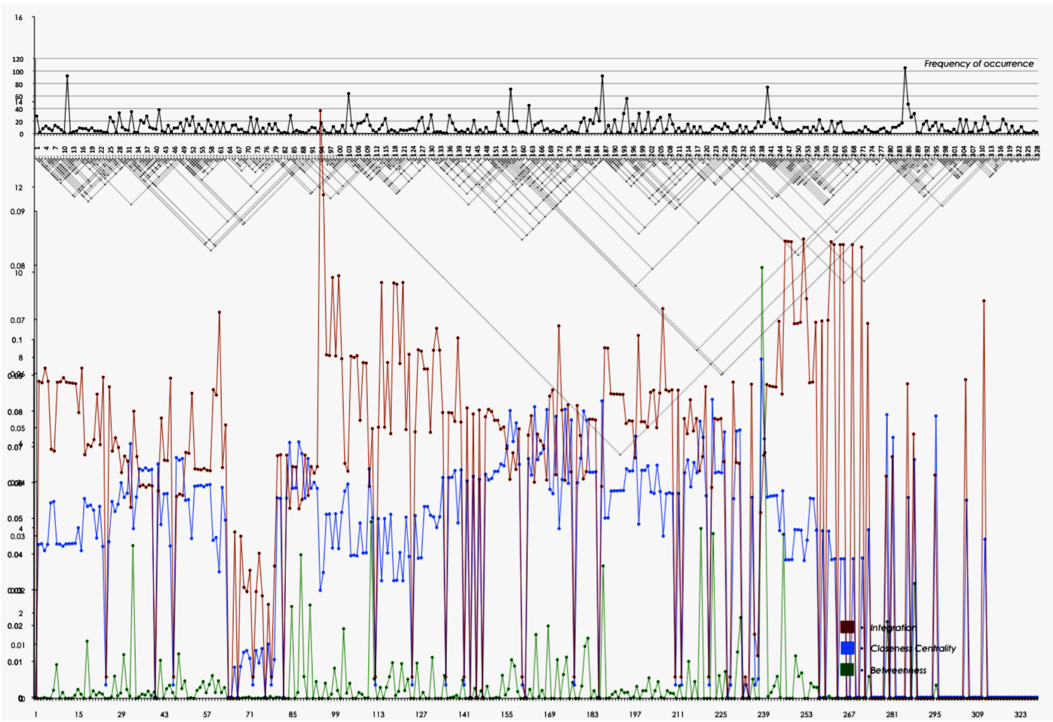


Figure 5.27b Syntactic and network analysis measures; integration, closeness centrality and betweenness for each design action

5.9 Results and Discussion

After conducting the analysis of two different design cases, Figure 5.28 presents the linkograph for each design processes, correlation values between integration, string measures (t-complexity and t-entropy), and centrality measures (closeness and betweenness) are investigated giving the values shown in Table 5.3:

Table 5.3 Values of correlation for two large linkographs

Variables of Correlation		Linkograph 1 (size n = 328)	Linkograph 2 (size n = 453)
Integration	***T-complexity***	0.23	0.23
Integration	***T-entropy***	0.22	0.23
Integration	***Closeness centrality***	0.73	0.85
Integration	***Betweenness***	0.07	0.21
T-complexity	***T-entropy***	0.99	0.98
T-complexity	***Closeness centrality***	0.46	0.39
T-complexity	***Betweenness***	0.37	0.24
T-entropy	***Closeness centrality***	0.46	0.39
Closeness centrality	***Betweenness***	0.37	0.41

According to the values of correlation listed in Table 5.3, both linkographs depict the following outcomes:

1. A significant direct correlation between *integration* and *closeness centrality* occurs in both cases. However, there is an inverse correlation between *integration* and *betweenness* in both cases.
2. A significant direct correlation between *t-complexity* and *t-entropy* particularly proves the earlier result that short strings computations are inaccurate and require to be inspected through large systems; however, both measures converge with long strings of information. This was confirmed throughout the analytical study on the case studies in this chapter as well as in the examinations presented in Appendix 5.1.
3. Integration and string measures are un-correlated, giving rise to the fact that both measurements identify different characteristics in the structure of multilevel networks. Since linkograph is a multi-complex network, integration identifies the multilevels of the structure because it is based on depth measure. However, string measures such as t-complexity and t-entropy are responsible for testing the arrangements of characters for the first level of direct relations only. Measures of integration and string t-codes might converge giving a direct correlation value only if the structure of the network is very shallow. The shallower the structure, the avoidance of the depth measure effect on the correlation estimation, the more probable that correlation integration and string t-codes can be achieved.

In developing an integrative approach for coding the dependency relations between the design actions it is crucial to further test the present results on various design cases. Our aim is to identify the design utterances, moves and episodes precisely to ensure the reliability of the quantitative method in order to identify the effect of sudden occurrence paradigm shifts on the structure of the design process. The emerging importance is to determine the level of reasoning structure of the utterances and relationships in a way that does not reach fragmentation impeding our understanding of the complexity of the design process, particularly the interdependence between the stages of the evolution of ideas.

We aim to construct a linkography network that will not be flattened with trivial segments or minor actions that have no adequate interpretation in terms of design actions and cognition, nor clustered with complex actions that might hide useful information that should better be segmented in order to understand the reasoning context beyond.[64]

[64] See Chapter 4, which investigates how to decompose the design process into meaningful levels through the series of events taking place in the preliminary experimental pilot case studies.

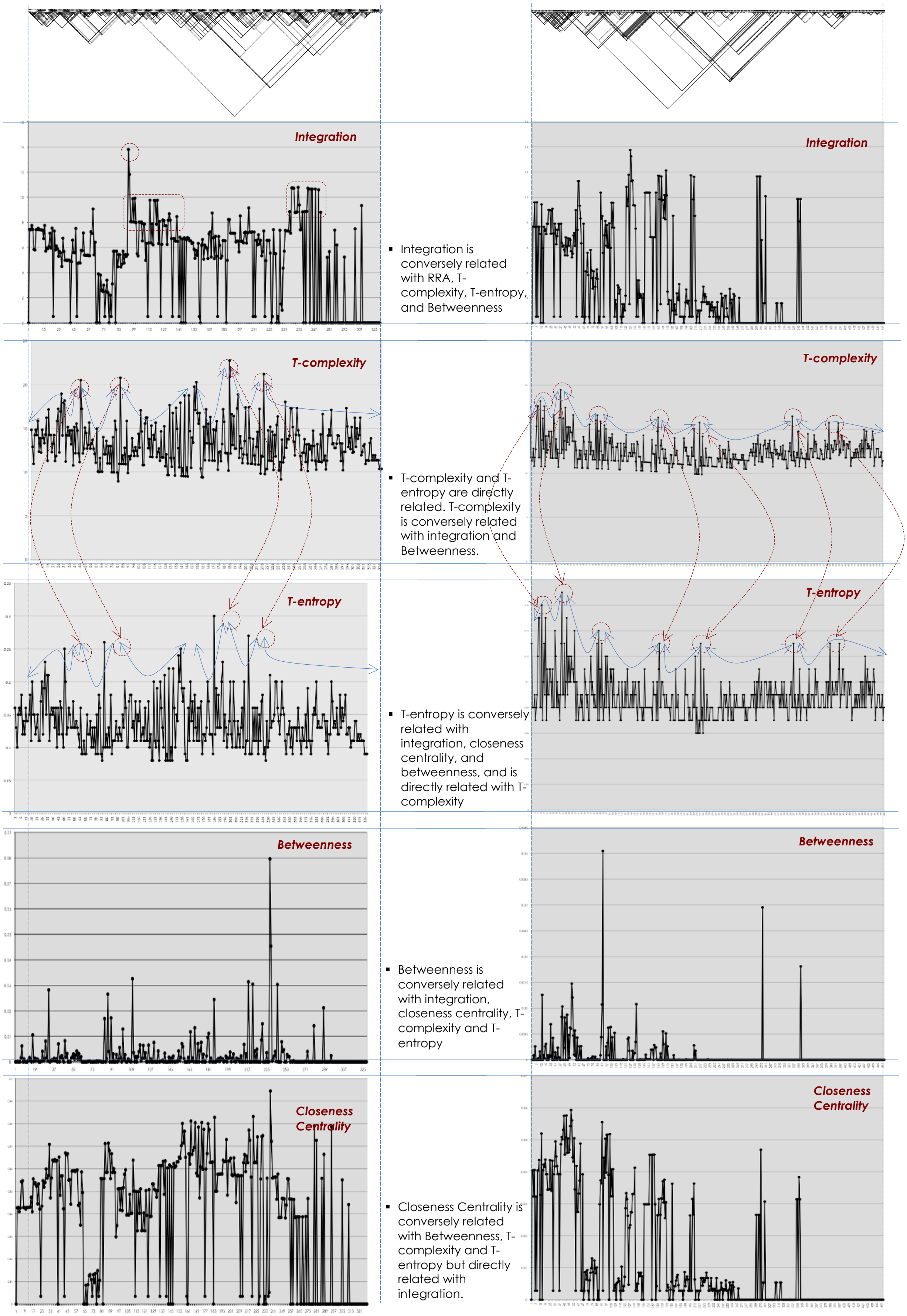


Figure 5.28 Quantitative measurements for the linkographs of two different design case studies

5.10 In Conclusion

In this chapter, we have been investigating the applications of certain measures that come from space syntax analyses of urban graphs to look at linkography systems. One hypothesis is that complexity is created from the local sub-graph at different scales in the graph system than from the whole system. Since linkography and urban systems deal with multilevel complexities, the overall goal of the proposed analytical method is to reveal the relationship between the parts (sub-systems) that constitutes the system and the whole.

Two perspectives are given: the entropy theorist looks at the overall distribution of sets of items that form the system while the information theorist looks at the individual sequence of items or the arrangement of sets that will probably occur. The application to linkography and the point depth entropy are examples of the former while the t-code computation of strings of information is adopted in this chapter to look at the latter. Two different contexts are given in the case studies. Since urban configurations and linkography systems are drawn from different characteristics, the assumption is thus made to examine whether the syntactical and string parameters receive similar correlation responses in both contexts or not.

The methodology merges syntactical and string measures to highlight the significant nodes in any system and investigate the proposed hypothesis: are highly intelligible systems associated with complexity and entropy? Since intelligibility, complexity, and entropy are 'system' properties, the method to process any system of 'n' size is an aggregation of 'sub-graphs' for each node in the system. The case studies include small and large systems, hypothetical and real. In order to highlight the significant nodes further, other parameters are added into the correlation: real relative asymmetry, closeness centrality and betweenness.

The relationships between string measures (t-complexity and t-entropy) and syntactical measures (integration and real relative asymmetry – RRA) are not clearly defined because of the inaccuracy of short barcodes. The assumption is then made that variable length barcode holds within it many possibilities and choices. Proving this hypothesis requires further investigation with larger systems. The more a node is connected to the surroundings, the greater the repetition frequency in the barcodes, the less predictable the information, and therefore low string complexity results. The asymmetry of the overall distribution of nodes within the system accounts for the 'associativeness' in the system and consequently gives an indication of the structure. RRA and integration values (inverse measures) can be tracked to trigger the degree of associativeness and incubation within the system.

The following conclusions are derived in light of the quantitative results: the shallower the structure of the network is, the more direct the correlation between depth (syntactic integration) and sequential (strings of information) measures, since the structure of relations became flattened. The development of a qualitative method to determine the design episodes and coding the relations is necessary to legitimise the reliability of the quantitative method.

The importance of this study lies, on one hand, from the definition it purveys about the responsiveness between the configuration of a system and the internal structure. On the other hand, it provides an analytical framework to acknowledge the degree of homogeneity between the 'parts' and the 'whole'. A study of a configuration that underlies arrangements of nodes is about the 'exposition' of facts that are called 'orderly' when the observer can grasp both their overall structure and the ramifications in some detail.

In conclusion, this chapter introduces a quantitative approach to examine the structure of networks in the linkograph. Methods are proposed for each single vertex representing a design 'move' in the graph, which can be relativised to the whole system and compared with the rest of the vertices. This paves the way for comparison between the local and whole networks of design configurations.

However, we stress the importance of examining the quantitative results alongside qualitative judgments of sketches and interim products; the 'contents' of actions taking place in the design processes. A joint approach of quantitative and qualitative analyses is applied to various design experiments and results are examined and discussed in following chapters. The goal of this joint approach is to avoid subjective interpretations precluding our analyses providing an integrative framework for *quantitative* and *qualitative* approaches. The next chapters 6 and 7 present the empirical study describing the nature of creative discovery in architectural design processes.

5.11 Key Findings of Chapter 5

- A quantitative method is developed to inspect the structural state of linkograph adopting information measurements.
- Application of syntactical depth measure (e.g. integration) can be investigated on the justified graphs to reveal the structure of relations beyond the emergence of creative actions (insights) that lead to the 'paradigm shift'.
- Critical in the design process are the bridging nodes that can be investigated to reveal their role on the transformation of concepts and/or the occurrence of creative ideas.

Table 5.4 Application of t-code string computation on ordered and structured linkographs via two computational methods: 'Concatenation' versus 'Backlink-directed' strings

#	Ordered - Sample 1				Ordered - Sample 2				Ordered - Sample 3				Ordered - Sample 4				Structured - Sample 1				Structured - Sample 2				Structured - Sample 3				Structured - Sample 4			
	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy	Concatenation Complexity	Backlinks Complexity	Concatenation Entropy	Backlinks Entropy
1	7.87	0	0.93	0	7.87	0	0.93	0	7.87	0	0.93	0	7.17	0	0.81	0	7.91	0	0.94	0	8.63	0	1.07	0	6.32	0	0.68	0	8	0	0.96	0
2	7.7	1	0.9	1.42	7.7	1	0.9	1.42	7.7	1	0.9	1.42	6.75	1	0.75	1.42	6.25	1	0.67	1.42	7	1	0.79	1.42	7.09	1	0.8	1.42	8.32	1	1.01	1.42
3	7.51	1.58	0.87	1.17	7.51	1.58	0.87	1.17	7.51	1.58	0.87	1.17	7.17	1.58	0.81	1.17	6.83	1.58	0.76	1.17	6.83	1.58	0.76	1.17	7.67	2	0.9	1.36	8.58	1.58	1.06	1.17
4	7.29	2	0.83	1.02	7.29	2	0.83	1.02	6.91	2	0.77	1.02	6.91	2	0.77	1.02	6.09	2.58	0.64	1.26	7.13	2.58	0.81	1.26	8.29	2.58	1.01	1.26	8.75	2	1.09	1.02
5	7.02	2.32	0.79	0.92	7.02	2.32	0.79	0.92	6.81	2.32	0.76	0.92	7.49	3	0.87	1.17	7	3	0.79	1.17	8	3	0.96	1.17	7.81	3	0.92	1.17	8.71	3	1.08	1.17
6	7.7	2.58	0.9	0.84	7.7	2.58	0.9	0.84	6.7	2.58	0.74	0.84	6.91	3.58	0.77	1.18	7	3.58	0.79	1.18	8	2.58	0.96	0.84	6	3.32	0.63	1.09	8.75	2.58	1.09	0.84
7	7.87	2.81	0.93	0.78	7.87	2.81	0.93	0.78	6.58	2.81	0.72	0.78	7.58	4	0.88	1.16	5.81	3.58	0.6	1.01	6.81	3.58	0.76	1.01	6.81	4	0.76	1.16	8.32	4	1.01	1.16
8	7.7	3	0.9	0.73	7.81	3	0.92	0.73	6.46	3	0.7	0.73	7.17	3.81	0.81	0.95	6.81	4.32	0.76	1.11	7.39	4	0.85	1.01	7.81	4	0.92	1.01	8.58	4	1.06	1.01
9	4.7	3.17	0.45	0.69	7.58	3.17	0.88	0.69	6.32	3.17	0.68	0.69	6.58	4.39	0.72	1.01	6.58	4	0.72	0.9	6.58	4	0.72	0.9	6.58	3.32	0.72	0.72	8.58	4.58	1.06	1.07
10	7.75	4.17	0.91	0.85	7.32	4.58	0.84	0.96	7.17	4.81	0.81	1.02	7.17	4.81	0.81	1.02	8.91	4.17	1.12	0.85	8.91	4.17	1.12	0.85	8.91	4.17	1.12	0.85	8.91	4.81	1.12	1.02
11	7.63	4.75	0.89	0.92	7	5	0.79	0.98	7	5	0.79	0.98	6.75	4.32	0.75	0.81	7.81	4.32	0.92	0.81	7	5	0.79	0.98	7.81	4.32	0.92	0.81	8.13	5.17	0.98	1.03
12	7.49	5.17	0.87	0.94	7.58	5.32	0.88	0.98	7.81	5.17	0.92	0.94	7.17	4.91	0.81	0.88	7.17	4.91	0.81	0.88	7.58	4.91	0.88	0.88	7.81	4.91	0.92	0.88	8.58	5.58	1.06	1.05
13	7.34	5.49	0.84	0.94	7.17	5.58	0.81	0.97	7.17	5.32	0.81	0.9	7.58	5.32	0.88	0.9	7.17	5.32	0.81	0.9	7.17	5.32	0.81	0.9	7.17	5.32	0.81	0.9	8.58	5.91	1.06	1.04
14	7.17	5.75	0.81	0.94	7	5.81	0.79	0.95	7	5.46	0.79	0.87	6.75	4.7	0.75	0.71	8.17	5.17	0.99	0.81	8.64	5.17	1.07	0.81	8.58	5.17	1.06	0.81	9	6.39	1.14	1.08
15	6.98	5.98	0.78	0.92	7.51	5.29	0.87	0.78	6.81	5.58	0.76	0.84	7.17	5.29	0.81	0.78	6.58	5.58	0.72	0.84	6.58	5.58	0.72	0.84	8.91	5.58	1.12	0.84	7.58	5.58	0.88	0.84
16	7.75	6.17	0.91	0.9	7.29	5.7	0.83	0.81	7.17	5.7	0.81	0.81	6.91	5.7	0.77	0.81	7.32	6.32	0.84	0.93	7.32	6.17	0.84	0.9	6.91	5.39	0.77	0.75	6.91	5.7	0.77	0.81
17	7.49	6.34	0.87	0.88	7.02	6.02	0.79	0.82	6.91	5.81	0.77	0.78	6.75	5	0.75	0.63	7.64	5.32	0.89	0.69	8.49	6.17	1.04	0.85	7.64	5.32	0.89	0.69	8.64	6.58	1.07	0.93
18	7.75	6.49	0.91	0.86	7.7	6.29	0.9	0.82	7	5.91	0.79	0.75	7.17	5.58	0.81	0.7	7.81	5.81	0.92	0.74	8.58	6.58	1.06	0.88	7.81	5.81	0.92	0.74	8.81	7.32	1.1	1.03
19	7.75	6.63	0.91	0.84	7.87	6.51	0.93	0.82	7.87	6.51	0.93	0.82	7.58	6	0.88	0.73	7.39	6.39	0.85	0.8	7.39	6.39	0.85	0.8	7.81	6.39	0.92	0.8	7.39	6.39	0.85	0.8
20	7.75	6.75	0.91	0.82	7.7	6.7	0.9	0.81	7.7	6.7	0.9	0.81	6.25	5.25	0.67	0.58	7.81	6.81	0.92	0.83	8.58	7.58	1.06	0.97	7.49	6.49	0.87	0.78	8.58	7.58	1.06	0.97
21	7.87	6.87	0.93	0.8	7.87	6.87	0.93	0.8	7.87	6.87	0.93	0.8	6.83	5.83	0.76	0.64	7.41	6.41	0.85	0.73	8.13	7.13	0.98	0.85	7.81	6.81	0.92	0.79	8.91	7.91	1.12	0.98

Chapter

6 Creative Discovery and Design Reasoning in Unstructured Architectural Case Studies

Validation of the proposed descriptive scheme

This chapter investigates the role of creativity in design reasoning in unstructured design processes. We examine an open-ended brief to design an expo pavilion. The validation of the descriptive scheme is tested against three solo design case studies. The architects vary in experience and knowledge. An integrative framework of qualitative and quantitative analysis is applied to facilitate our investigation to describe the emergent actions and evolution of ideas in the design processes.

Knowledge and *familiarity* are essential factors that play a significant role while making decisions in the design process. Architects who have gained knowledge through experience accumulated in a particular type of design project can recall the most important decisions when designing the same type of project in the future, whereas they face a difficult situation if they are not fully aware of the requirements and functional needs of projects of which they have no prior experience. The former case is examined in this chapter and the latter case is examined in Chapter 7. This chapter aims to demonstrate the formation of concepts, evolution of creative actions, and diversity of outcomes in design processes. In three solo design experiments, it examines the architect's ability to build the conceptual idea, discuss and reflect actions on the given brief and resulting artefacts, and form creative concepts within different design contexts. We have chosen an *Expo Pavilion* design task for Expo 2010 Shanghai, China, to examine three expert architects each with more than ten years' experience. We will adopt the integrative approach of qualitative and quantitative analysis (developed and proposed in Chapters 4 and 5) to describe the emergence of insights, evolution of ideas and formation of concepts in each case study. During the discussion of results, we will reflect on those views that stem from the technical rationality versus epistemology of practice paradigms, aimed at understanding the nature of design processes and creative discovery. We will address and discuss procedural and contextual components in architectural design processes.

6.1 Context of Experiments

Three chartered architects from the UK, Greece and Egypt were invited to participate in this experimental study, where each would individually design a pavilion that represented the image of his/her own country in the international forum of *Expo 2010 Shanghai*. The design briefing was given to the architects just before the design process commences. They had not received any information previously to avoid any direction towards preconceived projects, advance research or intrusion of particular (deliberate) mental imagery that might preclude the objectivity of the context of experimentation and data collection.[65]

The criteria for inviting these architects were: (1) years of experience, and (2) diversity of education and design themes, and familiarity, knowledge and practice of certain projects and building regulations. For example, the Greek architect, chartered in Greece and the UK, was specialised in lighting design. The British chartered architect had a wide experience of building science applications in industry, Royal Institute of British Architects (RIBA – Part III) and member of the UK Architects Registration Board (ARB). The Egyptian architect was a chartered member of the Egyptian Society of Architects and Engineers and had wide experience in academia and industry.

We will look first at the brief given to the three designers and then at the individual designers in a design experiment and the products designed. The compatibility between the quantitative and qualitative results is central to assessing the adequacy of this model.

[65] Instructions prior to the experiment and health and safety, and consent forms are included in Appendix 3.2. All the experiments were hosted at the Bartlett School of Graduate Studies, University College London.

6.2 Case Study 1: Unstructured, Unspecified and Open-ended Design Brief

Each architect was asked to design a pavilion for Expo 2010 Shanghai, with the aim of reflecting the image of a country from his/her own perspective. The brief was deliberately left open-ended with no specific functional requirements, constraints, regulations, or any predefined conditions/structures, to give free rein for design; see Figure 6.1. The conceptual idea was to be presented via any means of representation without any specific drawings or projections being requested and with no intrusion from the researcher. The time allowed for this design experiment was one hour. The process was video-recorded and the designer was asked consequently to comment retrospectively on the conceptual idea(s) and interim artefacts for the serial order of sketches produced in the session. The design reasoning was examined through the types of linkography networks. This can be signified through the following hypotheses:

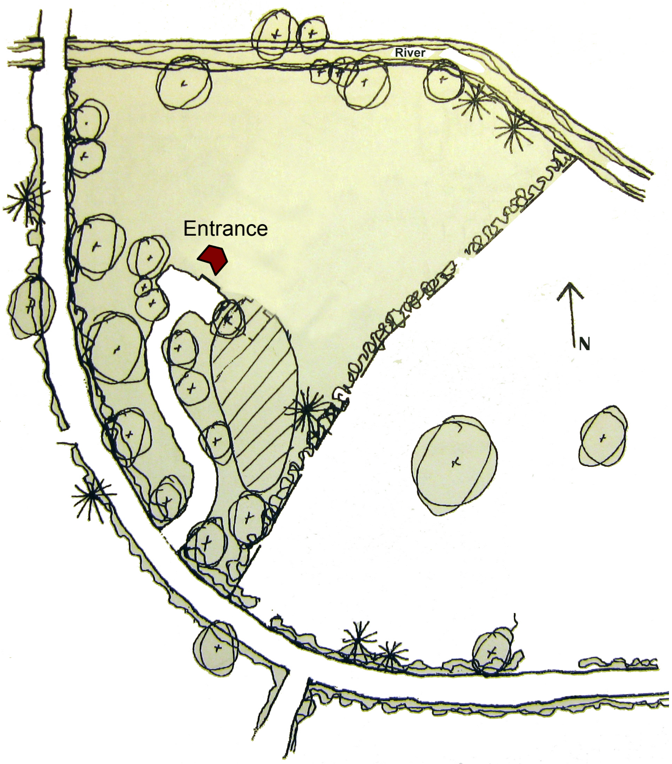
1) The mode of reasoning is incremental when the chunks of links are displaced along the linkograph in a consistent form; the process is not insightful and the pattern has no long *back*- or *forelinking*. This is the *transformational* mode.
2) The mode of reasoning is insightful when the chunks of links are highly structured; the pattern fluctuates along the linkograph with long *back* and *fore* synthesis. This is the *hierarchical* mode.

Our proposition for coding the dependency relations between design actions considers the overlap between media sketching episodes (the common actions between different sketches, e.g. physical and/or conceptual elements and idiosyncrasies) and their relation to reasoning. The concept can be developed, transformed or shifted entirely. Our objective is to reveal the relation between the contents and structure of reasoning. This chapter looks at:

1) The context of emergence of creative ideas and forms of reasoning.
2) The effect of the unstructured design brief on the formation of concepts, emergence of sudden mental insights (paradigm shifts) and the structure of reasoning.

Expo Pavilion, Shanghai 2010, China:

Design Briefing



Scenario:

Dynamicity is vital to *pavilion* design. It could be attained and reflected through circulation areas, galleries, exhibits, lighting, etc. It revolves around usability of space where *people* shape spaces.

You are requested to design a pavilion expressing the image of your country in expo-2010, Shanghai. The participant is required to think about types of exhibits that reflect his/her conceptual idea.

Time is 1.0 hour. The purpose of this study is to generate as many solutions as possible. Drawings are left to the designer to express his concepts whichever is possible.

For more information about expo2010, please visit: http://en.expo2010.cn/

Good Luck

Figure 6.1 Design brief of unstructured architectural case study

6.3 Designer 1 – Case Study 1 of *Expo Pavilion Design*

6.3.1 Description of Concept Initiation

The architect started the process by designing key conceptual elements that refer to the nature of her country, Greece. Eight concepts were drawn in abstract forms: sea ripples – circulation in and around lakes; built environment – boxes and light; complexity – stepped, organic, or orthogonal forms; sun and sky; olive and lemon trees; colour scheme (blue, white, turquoise); rock and water; and strong shadows. The named pavilions were: (1) 'The stepped interlocking forms'; (2) 'The olive tree'; (3) 'The tunnel'; (4) 'Links and cities'; and (5) 'Rocks and water'. The designs were presented in three A2 freehand sketches, and, as specified earlier, without any imposed constraints or interference. Figure 6.2 shows captions for the interim and final products.

The primacy of the design concept revolved around the congregation of five pavilions, grouped in one site-plan, with each reflecting a unique conception and spatial experience for the users. The variety of conceptual elements allowed the designer to create different syntheses and distinguish each pavilion from the others. Some elements appeared in several pavilions but with different architectural treatments: e.g. 'embedding the concept of lighting' (using natural skylights, light wells or artificial interactive installations); 'peripheral circulation around central element' (pond, water ripples or olive tree).

'Natural lighting' was taken as a central concept in most of the pavilions. The concept was adopted in pavilions 2, 3 and 5 where a skylight treatment was commonly used. Tracking this idea from one sketch to another illustrates the *lateral transformation of concepts* beyond the evolution of interim artefacts: how the concept developed from one stage to another. This was investigated on two different scales: pairwise comparisons between the artefacts and for the whole configuration.

Sudden 'absence' and 'appearance' of conceptual elements through the interim artefacts created cues to examine the context beyond and search for the paradigm shifts and creative insights that might have occurred suddenly. Pavilions 1, 2 and 5 were strongly related to the preliminary set of conceptual elements: the 'stepped forms', 'olive tree', and 'rocks and water'. However, in spite of being produced in serial order, pavilions 3 and 4 – 'the tunnel' and 'links and cities' – had no direct relations with the preceding artefacts (few *backlinks* to the preceding actions). In particular, pavilion 3 of the 'tunnel' constituted a paradigm shift on the flow of prevailing concept. The concept was entirely independent. In her retrospective comments, the designer demonstrated the product and explained it as an idea that came up while designing.

Pavilion 2 of the 'olive tree' was designed on the synthesis of three concepts: 'sunlight', 'cubic interlocking forms' and 'olive tree' as a central element. The concept was developed through two sketching media of different projections: 2-D plan and 3-D perspective section. The idea was transformed and developed while switching three times between the sketching media. Switching points (from pavilion 1 to 2: node 23; the entire switches nodes: 27, 30, 47; and the ending node: 52) are shown in Figure 6.3 and Table 6.1.

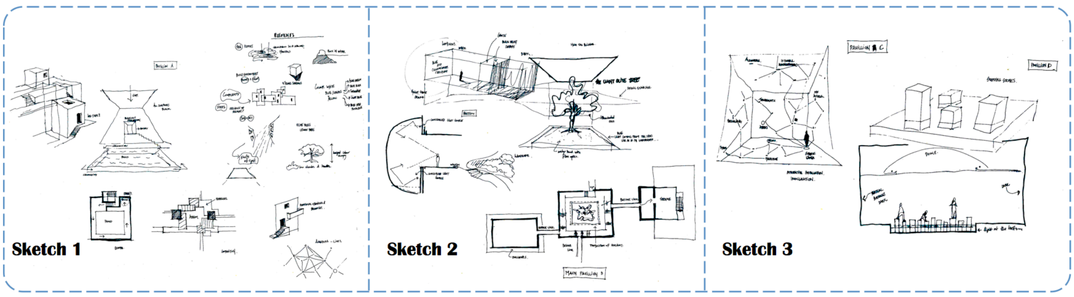


Figure 6.2 Illustration of sketches – The interim and final products of the design process (Case Study 1, Designer 1)

6.3.2 Transcription

Dependency relations between design actions are transcribed, coded and examined in the context of design process according to the order of occurrence of the interim artefacts[66] (see Figures 6.4a, 6.4b and 6.4c). The linkograph is constructed and starting and ending points are demarcated for each designing medium, including sketches, drawings, use of software applications, and any graphic material showing the actions that were pursued in each medium (see Figure 6.5).

Identification and marking up of the critical actions and sudden creative insights occurring in the process show the venues of transformation and paradigm shifts. Our approach to understanding the conditions beyond the formation of novel concepts and the structure of design process can be investigated through qualitative and quantitative analysis of linkography networks. *Sketching episodes* are the basic units to capture the structure of reasoning and examine the effect of sudden paradigm shifts.

6.3.3 Description and Qualitative Analysis: Identification of Critical Creative Actions

This early phase of *concept initiation* started with an *insightful* thinking process. The architect set up a variety of conceptual and key elements that represented the nature and quality of life in Greece. Some elements emerged surprisingly, causing sudden changes in the prevailing concept of sketching. Nodes 2 to 8, 11 and 15 are conceptual ideas that appeared in one sketching medium but independently.

The architect moved to another sketching medium and designed the first pavilion, the ‘interlocking and stepped forms’. Nodes 17, 18 and 19 are considered incremental actions that preserved the prevailing concept. Each of the three nodes represented a different architectural treatment: 3-D perspective (node 17), 3-D section (node 18) and 2-D plan (node 19). However, the sketching process did not go in only one direction between the three drawings. It switched *back* and *forth* to add masses and refine details. Nodes 17, 18 and 19 are considered creative moves that contribute to ‘reframing’ the prevalent solution through *advanced incremental* actions.

In the third sketch, nodes 25, 27 and 31 constitute three entire switches of three drawings to another prevailing concept: pavilion 2, ‘the olive tree’. These nodes are considered *vertical transformation* of the idea from one projection drawing to another. They constitute incremental reasoning in the structure of design process.

Node 52 is a *back reflection* action in the mind. Goldschmidt (1991) states two kinds of sketching process; the first transforms imagery into new forms of combinations (a *rational mode of reasoning*), and the second generates new imagery of forms in the mind (a *non-rational form of design thinking*). At action 52, the architect added a new conceptual element to the initiated set – a detail of *irrational openings and balconies* that distinguishes the architecture of Greece.

However, node 55 is a drastic sudden shift from the preceding concept. The design was switched to sketch pavilion 3 with a novel concept different from the irrational openings. The *lighting tunnel* is an artificial installation centred on the concept of *lighting* and *fading*. Node 55 is a sketching episode for a 3-D perspective while node 60 is an entire switch; a vertical transformation to design a 2-D longitudinal section. Node 55 is considered a sudden creative insight that has the quality of *redefining* the problem.

Node 71 is an occurrence of sudden mental insight. A paradigm shift occurred to design an unprecedented concept about the Greeks’ emigration around the world. Pavilion 4 is an interactive installation for ‘cities and links’ inspired by the 2011 Serpentine Pavilion in London designed by Swiss architect Peter Zumthor (different design each year). In her retrospective comments on this concept, the architect said: ‘I am also influenced by the Zumthor Serpentine Pavilion, which has everything to do with light’. The design was then continued through another projection of 3-D section at an entire shifting node at 72.

The last pavilion, 5, is a different concept from the preceding pavilion 4. It revolved around the elements of ‘rocks and water’, covered by a *skylight*, started from node 79, a sudden insight that,

[66] Full detailed *transcription* and *coding* analyses are shown in Appendix 6.1.

however, reflected synthesis with an early key element in the concept initiation phase, node 11. Node 82 is a forward incremental move that reframed this idea but in another sketch of 3D section. Table 6.1 identifies critical actions, sketching media and switching nodes, and modes of design reasoning.

6.3.4 Correlation with Quantitative Measurements

Correlating quantitative and qualitative analyses, this section aims to test the validation of the proposed model – whether the results are compatible with the preceding descriptions. Further, we aim to describe the significance of quantitative measures in light of the qualitative descriptions. The methods of *directional* computation of backlinks and *concatenation* of back- and forelinks exemplify the significant nodes in two different situations. Table 6.2 shows results for each method.

In this chapter, we are concerned with describing only the undirected measures, looking at the concatenation of *backlinks* and *forelinks* to describe the role of critical actions through the whole process.[67] Thus, the following integration measures are introduced to investigate the structure of linkograph. Identification of the critical moves and creative insights in the design process is based on the qualitative judgements of interim artefacts. As a rule of thumb:

- High integration → low mean depth → low relative asymmetry:

    - *The mean path length (Li) – the average number of steps to move from the vertex to reach any other vertex in the network using the shortest number of steps possible – is a 'linear' sequence of relations. Few steps are required to reach the end of the system.*

- Low integration → high mean depth → high relative asymmetry:

    - *The mean path length (Li) – the average number of steps to move from the vertex to reach any other vertex in the network using the shortest number of steps possible – is a 'non-linear' sequence of relations. Many steps are required to reach the end of the system.*

- Median integration → average mean depth → average relative asymmetry:

    - *The mean path length (Li) – the average number of steps to move from the vertex to reach any other vertex in the network using the shortest number of steps possible – is a 'non-linear' sequence of relations. A moderate number of steps are required to reach the end of the system.*

- High t-code measures → diversity of arrangement of sets → the variety of sets of codes in a complex pattern increases its probability.
- Low t-code measures → repeating pattern of codes → the monotonous arrangement of sets of codes reduces the pattern's diversity and probability.[68]

In order to investigate the main research question; whether *the relation between the contents of design and the structure of reasoning is hierarchical or transformational, can a solution evolve bottom-up from its parts*, and *the role of sudden paradigm shifts in the design process*, the following principles are examined in the context of experiments:

[67] See Chapter 8 to review the role of critical actions based on the correlation between directed and undirected depth measurements.

[68] Concatenated strings of information is a method that identifies the rate of information and complexity of bits of information (the arrangement of the bits that form a string of codes '0's and '1's. This method has three values that can be computed for any node in the linkograph, which is based on the back-relations and fore-relations for each node.
The three measurements are:
t-complexity → unit is: taugs
t-entropy → unit is: bits/char
t-information (which I am excluding here)
Centrality measures are types of 'network analysis'. This is another method (different from strings of information) that identifies the structure of the network. Two measurements used here are: Closeness centrality and Betweenness centrality.

- A hierarchical design process reflects a structured way of thinking. To move from design step '1' to '3', you have to pass through '2'. The evolution of idea occurs incrementally, where the action for each step *reframes* and *preserves* the prevailing concept. The assumption of concept is made ahead of the design process (at the early stage of concept initiation) and the architect sets a strategy of design actions to achieve it. Actions imposing a structure of links of certain concepts on the following interim artefacts are considered to be at the top of a hierarchical design structure.
- A transformative design process shows a mutual effect between the mind and interim artefacts in the formation and development of concepts. Sudden insights are likely to occur in the reflections that can be unexpectedly elaborated with the sketches.
- Modes of sketching represent a transformative process: sketching to transform imagery into new forms (rational mode) and sketching to generate new imagery of forms in the mind (*non-rational form of thinking*) (Goldschmidt, 1991).

In this design case, the following results are retrieved within the whole linkograph:

- The highly connected node is 31 with 25 links (9 *backlinks* and 16 *forelinks*), delivering the maximum t-code values.
- The highest global integration is 5 with a value of 2.92 (a sketching episode of the conceptual element of the 'olive tree').
- The lowest integration is delivered through node 71 with zero value, reflecting a flattened network.

Node 24 is a back-reflection; *sketching back* to reframe the idea of 'composition of overlapping terraces' into the conceptual set. In one sketching episode 'masses around a central atrium' were drawn as a concept to assemble a *parti* (conceptual artwork) of the independent pavilions. This conceptual idea was framed after the design of the 'stepped form' pavilion (nodes 17 to 23). Node 24 delivers median integration of 1.72 and high t-code sets: t-complexity 14.45 (taugs) and 0.58 t-entropy (bits/char).

At node 25, the designer paused from sketching and glanced at the brief. Investigating the context of sketching before and after node 25, two sketching episodes occurred: at node 24, a new form was uploaded to the conceptual set of elements, titled 'composition of terraces and overlapped masses'; while at node 26 the concept shifted to designing the 'olive tree' pavilion after a thinking pause. Thus, node 25 is considered to be *disconnection* in the train of thought. Node 25 delivers median integration value 2.00 representing a relatively median network on balance to the overall system and low t-codes measurements: t-complexity 7.93 (taugs) and 0.24 t-entropy (bits/char).

Node 31 is a *bridging* node that delivers the highest t-code values: t-complexity 17.98 (taugs) and 0.8 t-entropy (bits/char). It is a shift to address the prevalent concept of the 'olive tree' pavilion in a new sketching episode of a different projection (shifting from 3-D perspective to 2-D plan). It reflects a vertical transformation, enhancing the concept through a new projection. Exchanging the idea *back and forth* between different sketches (2-D and 3-D) is an explicit form of the mutual reflection between the sketching medium and the mind (between two *cognitive structures* of internal and external representations). Node 31 delivers median integration value 1.57, representing a median network in relation to the overall system.

Node 52 is also a back-reflection about 'irrational openings and balconies'. The designer went back over this diagram to add to the first set of elements after designing the 2-D plan of the 'olive tree' pavilion that extended from nodes 31 to 51. It delivers median integration 1.7 and high t-code sets: t-complexity 13.63 (taugs) and 0.53 t-entropy (bits/char).

At node 53, the concept 'irrational openings and balconies' was drawn: a new element that generated new syntheses of form in the mind (which might be obtained again later in the designing discourse). It delivers median integration value 1.44 of a median network. This is a transformative action resulting from the reflection-in-action process with the artefacts. It delivers median integration 1.44 and low t-code sets: t-complexity 8.09 (taugs) and 0.25 t-entropy (bits/char).

The sudden occurrence of node 55 is a drastic change of state. At this moment, the designer diverted her train of thought from designing the 'olive tree' pavilion to designing the 'light tunnel'. It is a spectroscopy of various colours and a gradual diffusion of artificial light. Using 'lighting installations' as the prime concept is introduced in the design process for the first time at this node. It delivers median integration 1.34 and median t-code sets: t-complexity 11.69 (taugs) and 0.42 t-entropy (bits/char).

Likewise, node 71 is a *rupture* event in the activity – an independent sketching episode from node 70 of the 'tunnel' pavilion 2-D section. At node 71, a sudden event occurred to design a new element, entitled 'cities and links' – the dispersion of the Greek community around the world – on a different sketch. Despite being disconnected from the linkography network, node 71 has strong linking relations with the following actions until the completion of the pavilion at node 78. This concept imposes a specific structure on the following actions and reflects constructive thinking and a hierarchical relation between the contents and reasoning. The evolution of idea evolved top-down considering the 'form–function' relation at the level of the whole configuration. It delivers median integration value 1.38 compared to the whole linkograph and low t-code sets: t-complexity 9.32 (taugs) and 0.3 t-entropy (bits/char).[69]

Figure 6.6 presents annotations of creative actions, contents of sketching, the transformation of concepts through the variety of media and back/forelinking on the linkograph. Figures 6.7, 6.8 and 6.9 show different overlays of quantitative measures on the linkograph; undirected (global) vs. directed (local) integration; the proposed methods of computing strings of information undirected vs. directed computation; and network analyses application. Figure 6.10 illustrates the distribution of nodes according to the strength of connectivity among the nodes in the linkograph.

6.3.5 Results and Discussion

From the integrative model of qualitative and quantitative analyses, we are able to detect the critical creative actions and the role in developing and transforming the concept from an abstract idea to a spatial configuration. We are able to describe the design situation based on the basic units in the structure of reasoning and, further, to quantify the integration of nodes in the linkograph in several ways.

Two levels are denoted to inspect the relation between contents and structure of reasoning: (1) a level of continuous forward sketching and externalisation of ideas; and (2) a level of back-reflections to generate imagery of forms in the mind (represented by adding new design elements to the preliminary set of concept initiation). Figure 6.3 presents variety types of sketching episodes and reasoning of design.

The sudden occurrence of a creative idea restructures the design problem and paves the way to a new solution to emerge bottom-up. This paradigm shift constructs the following actions in order to achieve the design of the new concept. In this way, sudden insights change the process to become pyramidal top-down. The relation between the design contents and the structure of reasoning is hierarchical in this case. However, in the rational ideal mode of designing, the relation can take a transformational mode, where actions reflect back and forth on each other. This pyramidal case can be detected via the linkograph, where actions are linked to a certain node (sudden insight), while in the transformative case the linkograph network is more structured with various links of relationships.

Comparisons between the quantitative measurements can be achieved from these computational methods because all values are relativised to the 'n-size' of the system. This is one of the main characteristics owing to the deterministic information theory and t-code sets. The correlation between a spatial measure (integration) and t-code sets of information is not applicable due to the difference between the characteristics of both measurements. Association between measures and the qualitative description of contents (e.g. *interim design artefacts* or *cognitive activities*) provides a robust method to identify the conditions beyond the formation of novel concepts. El-Khouly and Penn (2012a) distinguished the variety of configurations of linkographs that can be observed occurring in the design process: orderliness, structured and disorderliness characteristics.

Figures 6.7, 6.8 and 6.9 show how the multiple exchanges of ideas between different sketching media have a role in the synthesis process and high probability for sudden creative insights to occur. The

[69] The illustration of pavilion 4 shows names of different cities to which Greeks immigrated, e.g. Melbourne, London, Istanbul. The architect called this pavilion 'Interactive Installation Immigration'. The names of cities are symbolised by dispersed nodes in a cubic form and connected with illuminated links. Colours and lights are embedded in ways that are unique from the preceding interim pavilion designs. The idea has intruded into the prevailing flow causing a paradigm shift in this way.

networks of pavilions 3 and 4 appear respectively semi-connected to or disconnected from the whole linkograph. The integration measure shows the depth of ideas while t-code sets demonstrate the complexity of strings of information at each single node in the graph, which reflects the outer surface of relations only. Therefore, no significant fluctuation is seen with t-codes compared to integration values. A change of state is often revealed through *integration* (depth measure) not through *t-complexity* and *t-entropy* values.

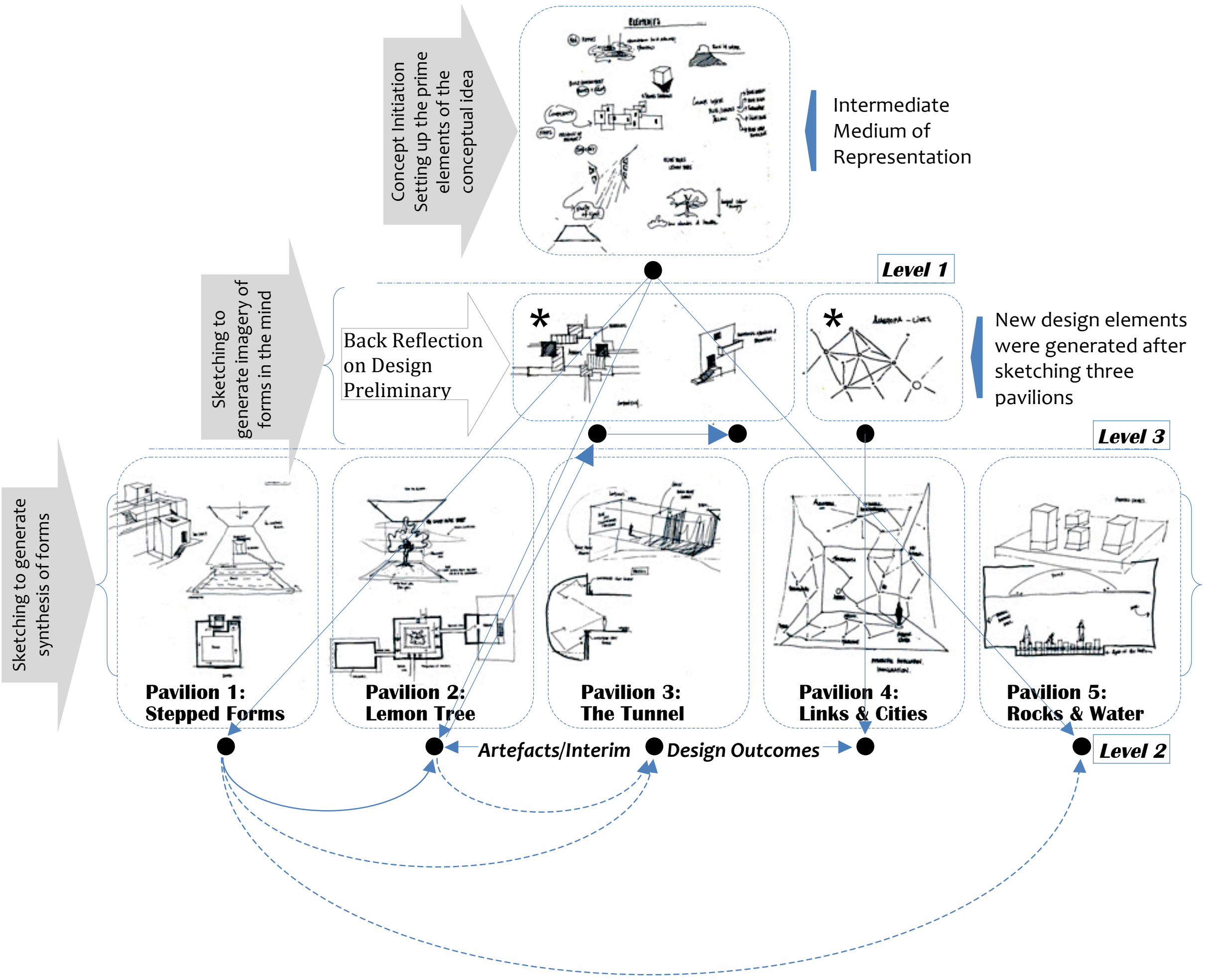


Figure 6.3 Types of sketching episodes and reasoning of design (Case Study 1, Designer 1)

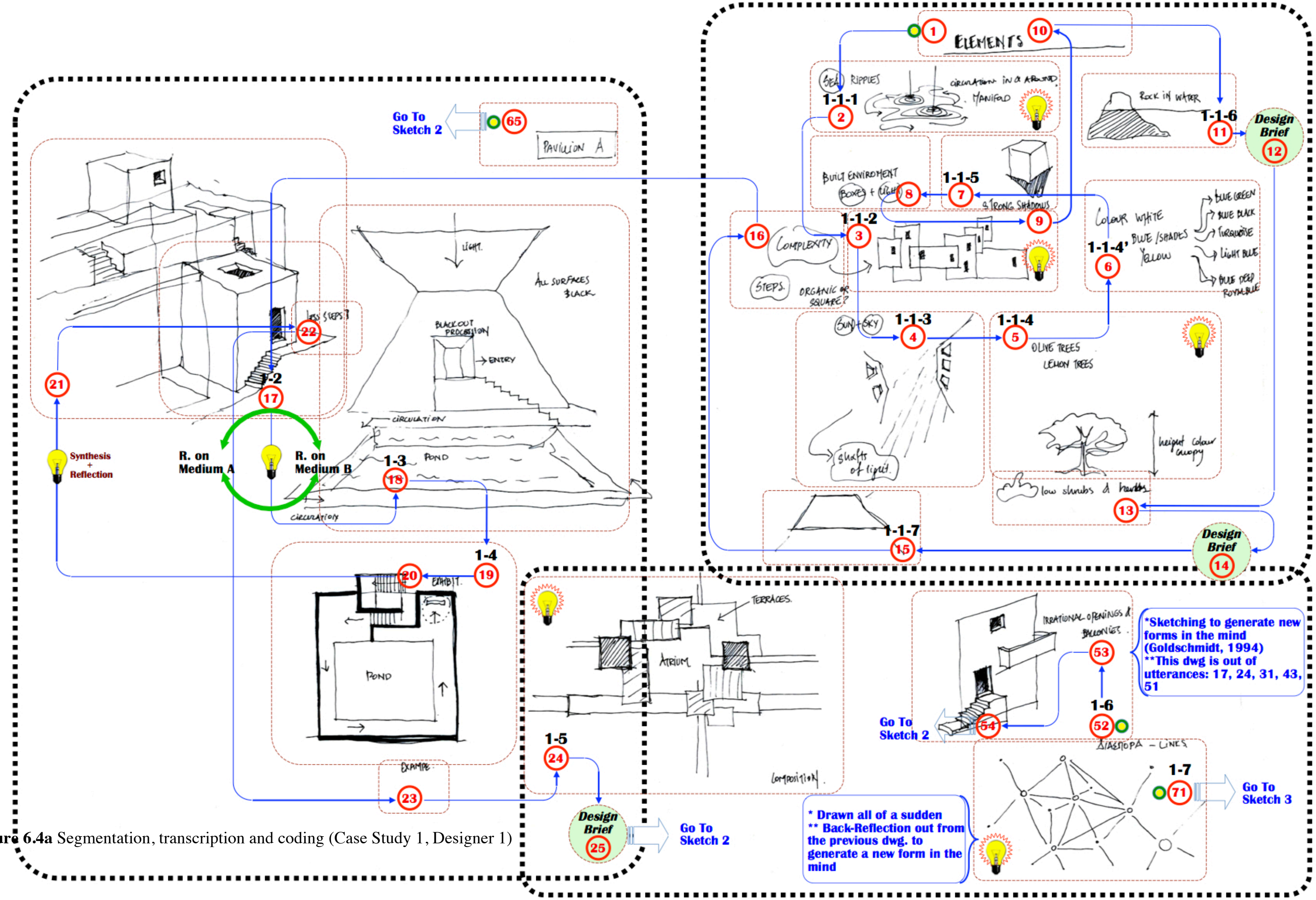


Figure 6.4a Segmentation, transcription and coding (Case Study 1, Designer 1)

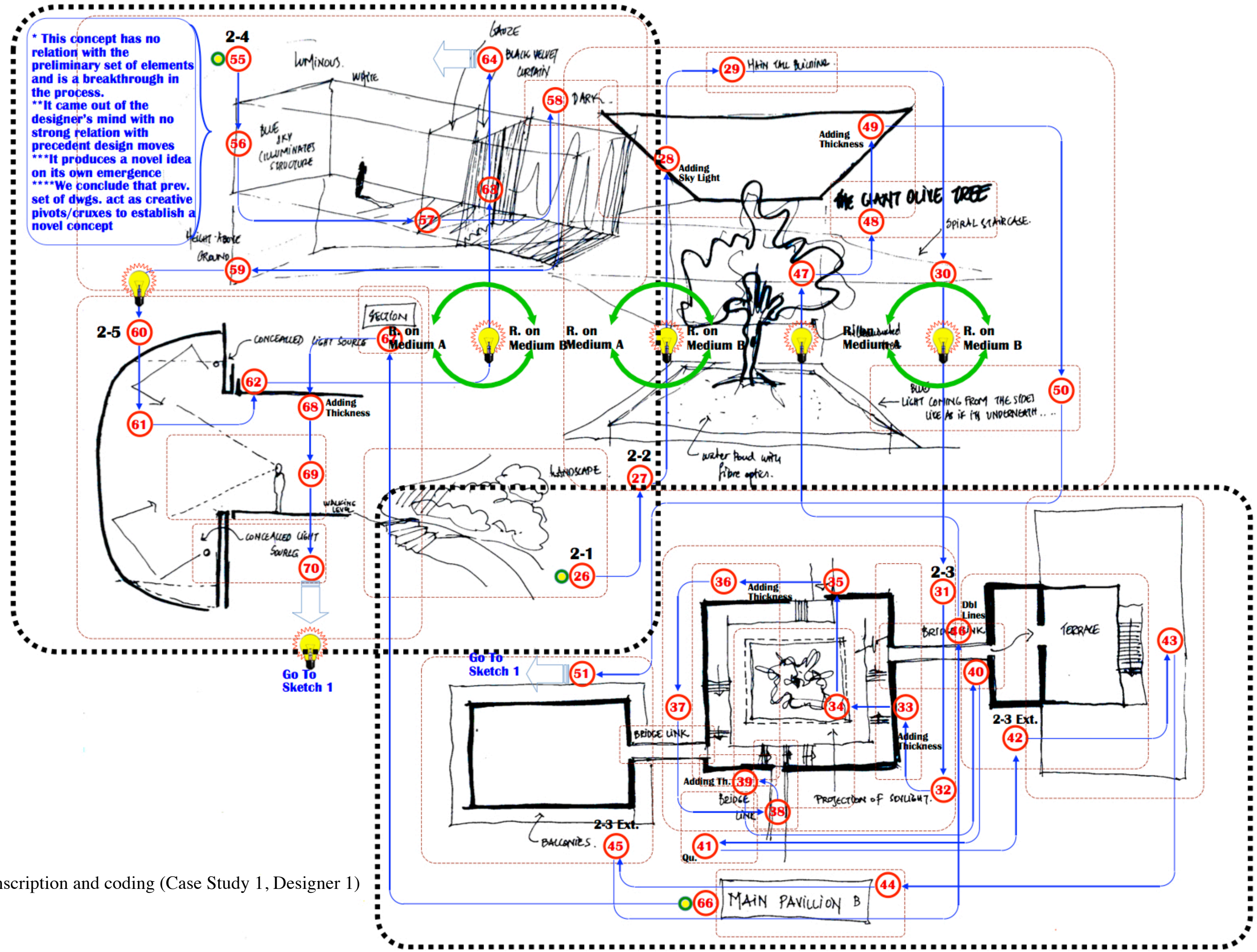


Figure 6.4b Segmentation, transcription and coding (Case Study 1, Designer 1)

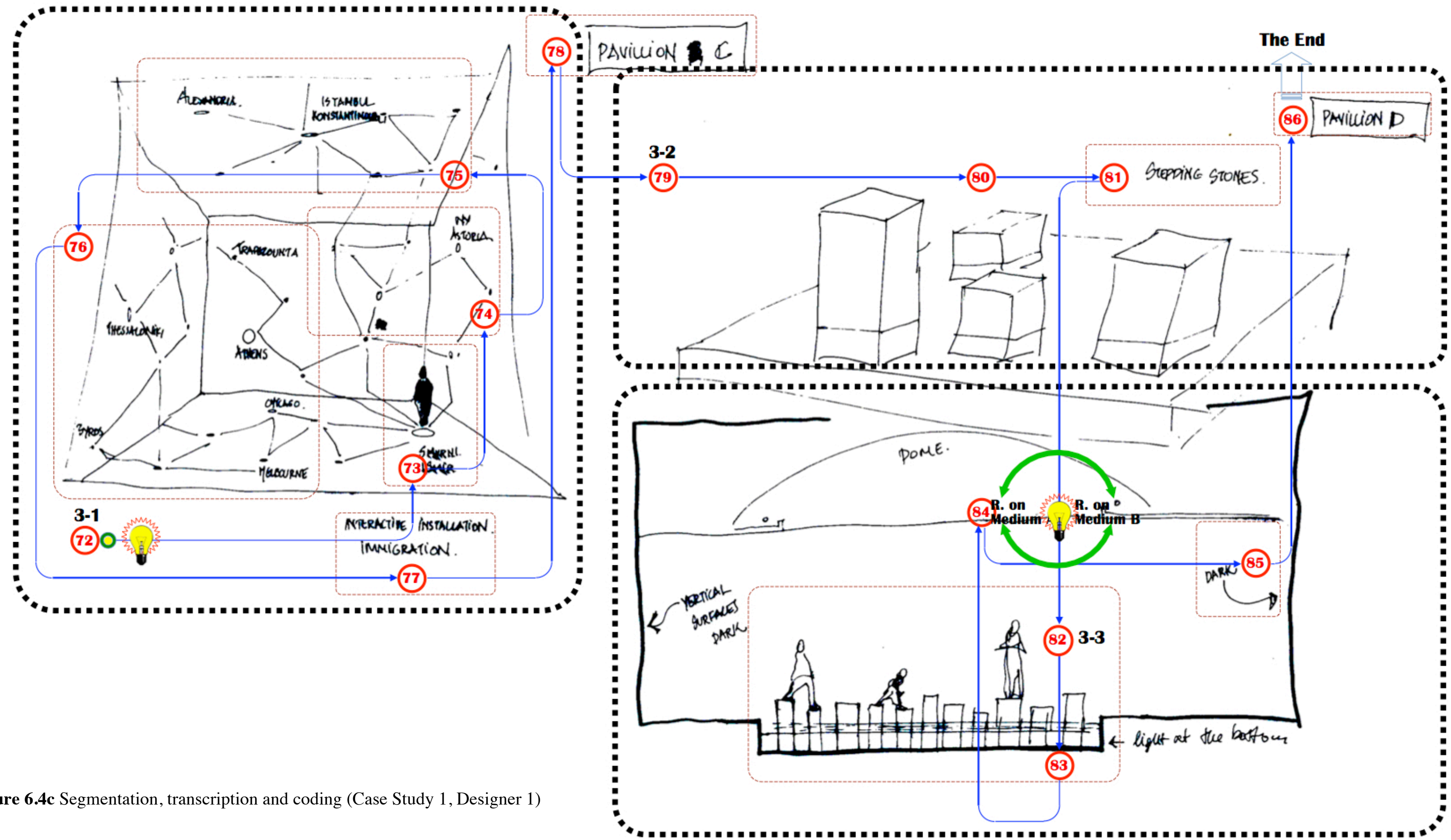


Figure 6.4c Segmentation, transcription and coding (Case Study 1, Designer 1)

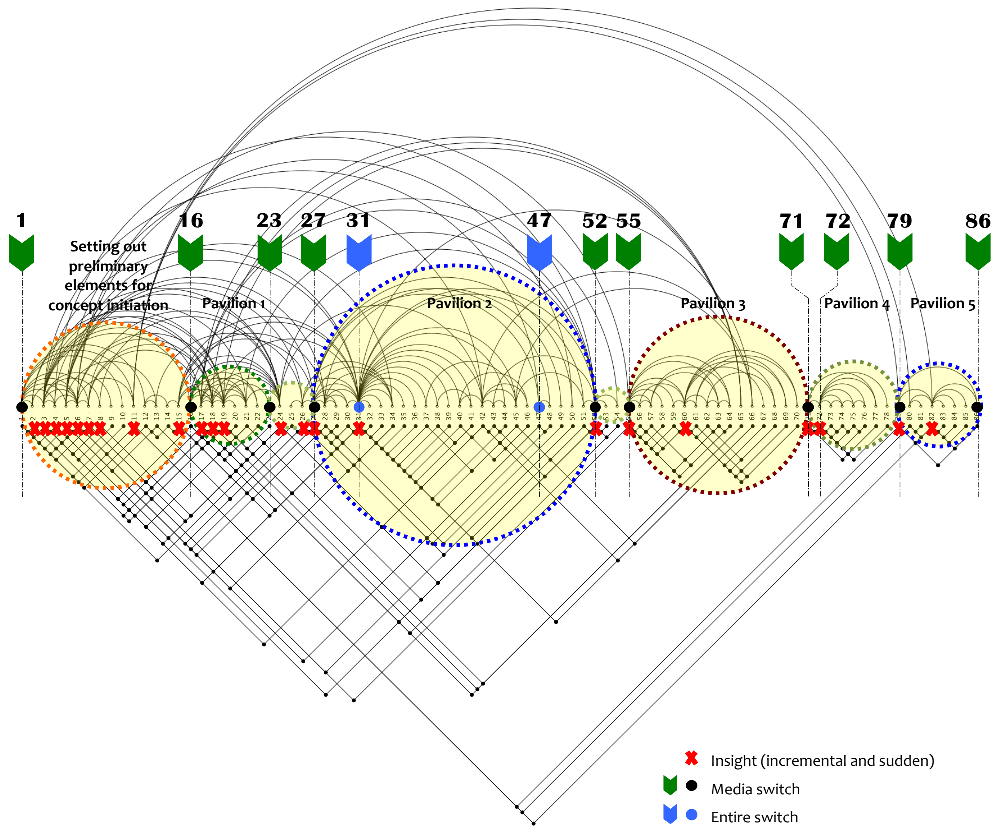


Figure 6.5 Illustration of linkography and archiography media graph overlaid with media switches cutting points and marked up with creative insights (Case Study 1, Designer 1)

Table 6.1 Descriptions of the emergence of insights and formation of concepts referral to design media and switching (transferral) nodes

Medium Sketch	Concept	Significant Actions		The impact of the structure of reasoning on the emergence of insights
		Entire Switching Nodes	**Media Switching Nodes**	
Conceptual set	*Elements of the image of a country*	2, 3, 4, 5, 6, 7, 8, 11, 15	25, 52, 71	Incremental insights – except 25, 52, and 71– are sudden back reflection to the mind
Pavilion 1	*Interlocking stepped forms*	17, 18, 19	–	Incremental insights and entire switches of one former concept
Pavilion 2	*Olive tree*	27, 31	26	26 is a sudden insight while 27 and 31 are incremental insights; entire switches of one former concept
Pavilion 3	*Lighting tunnel*	60	55	55 is a sudden insight while 60 is an incremental insight; entire switch
Pavilion 4	*Links and cities*	72	71	71 is a sudden insight while 72 is an incremental insight; an entire switch of a former concept
Pavilion 5	*Rocks and water*	82	79	79 is a sudden insight while 82 is an incremental insight; an entire switch of a former concept

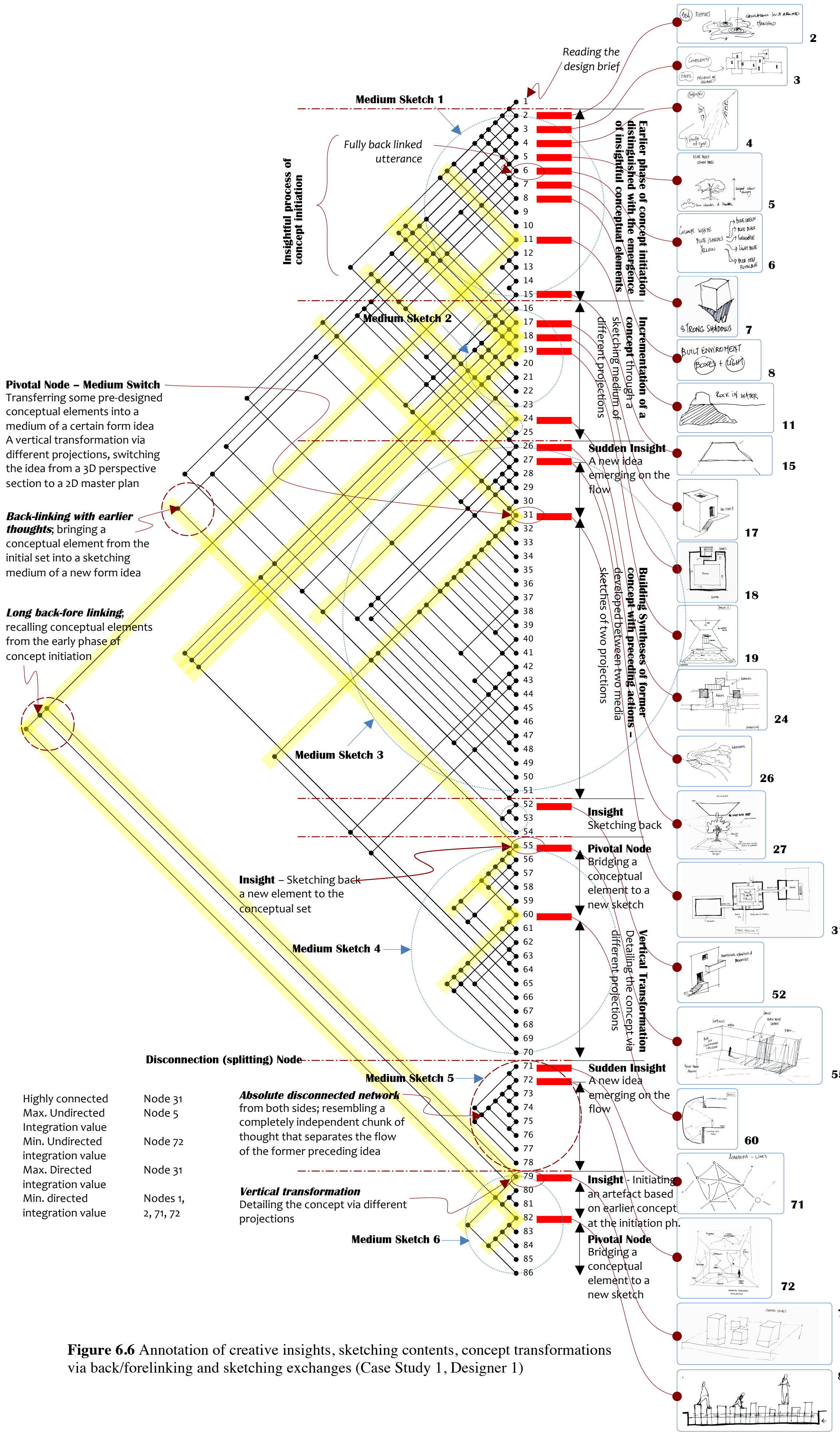


Figure 6.6 Annotation of creative insights, sketching contents, concept transformations via back/forelinking and sketching exchanges (Case Study 1, Designer 1)

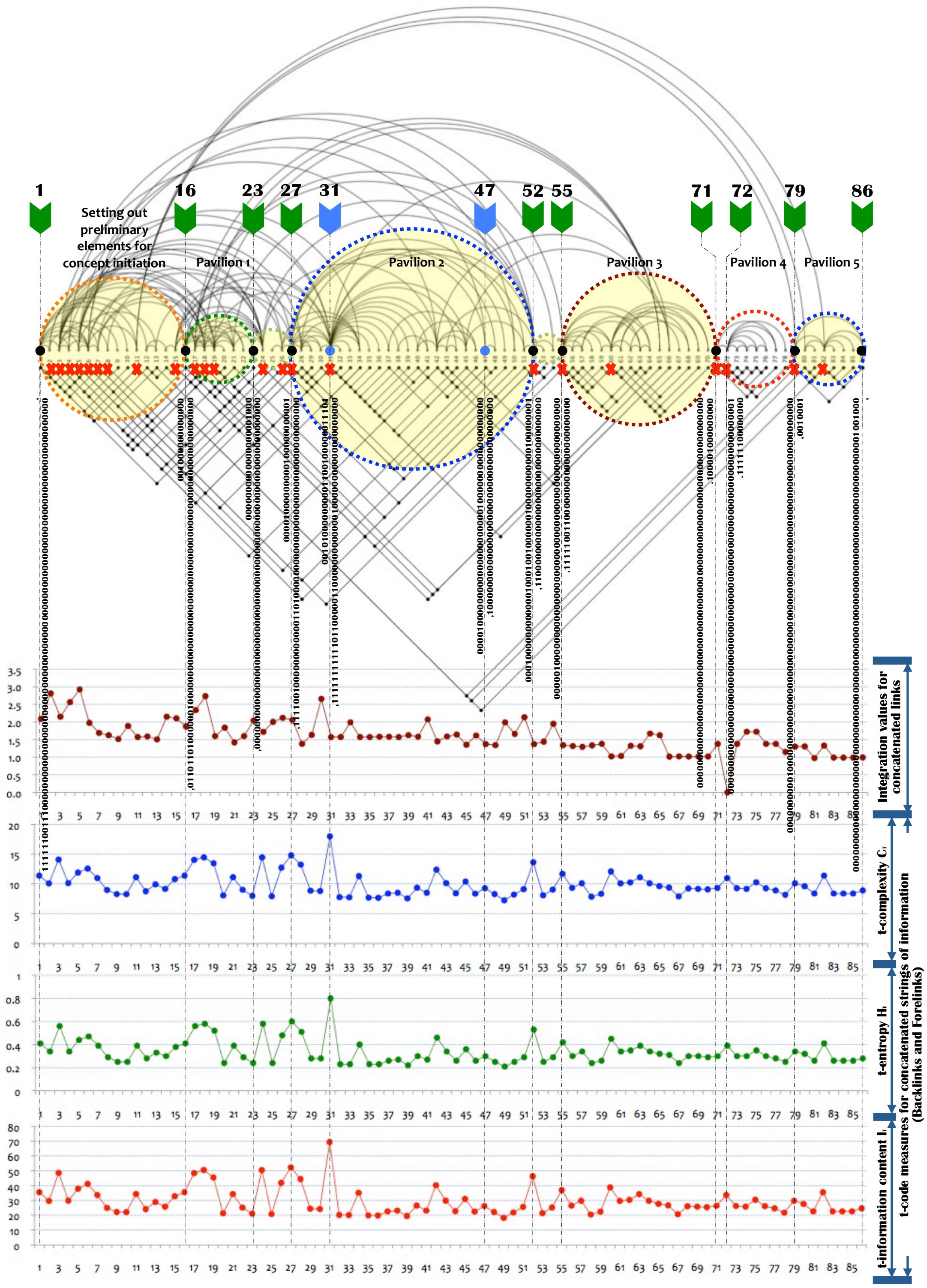


Figure 6.7 Quantitative measures for *concatenated* relations (Case Study 1, Designer 1)

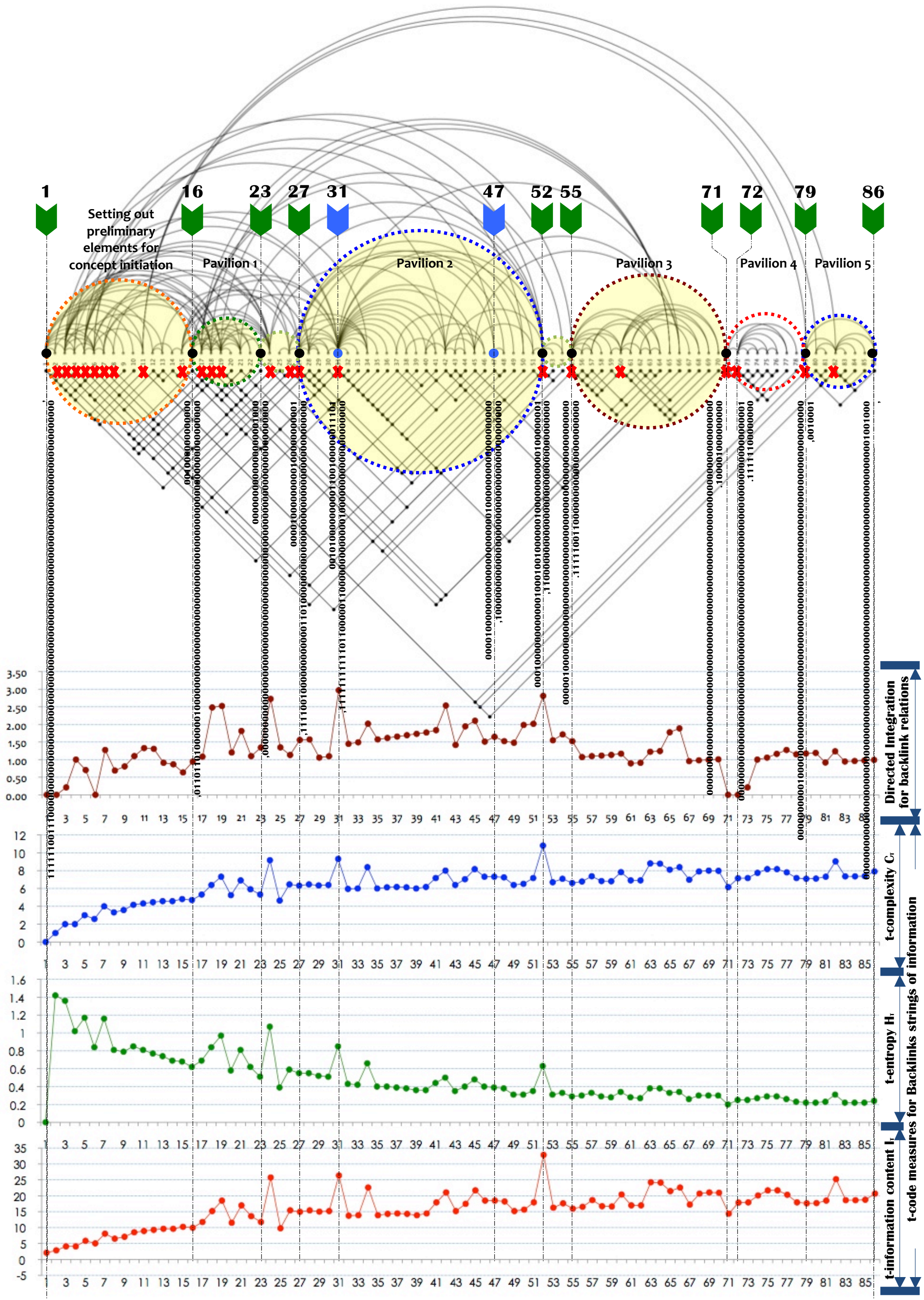


Figure 6.8 Quantitative measures for *backlink-directed* relations (Case Study 1, Designer 1)

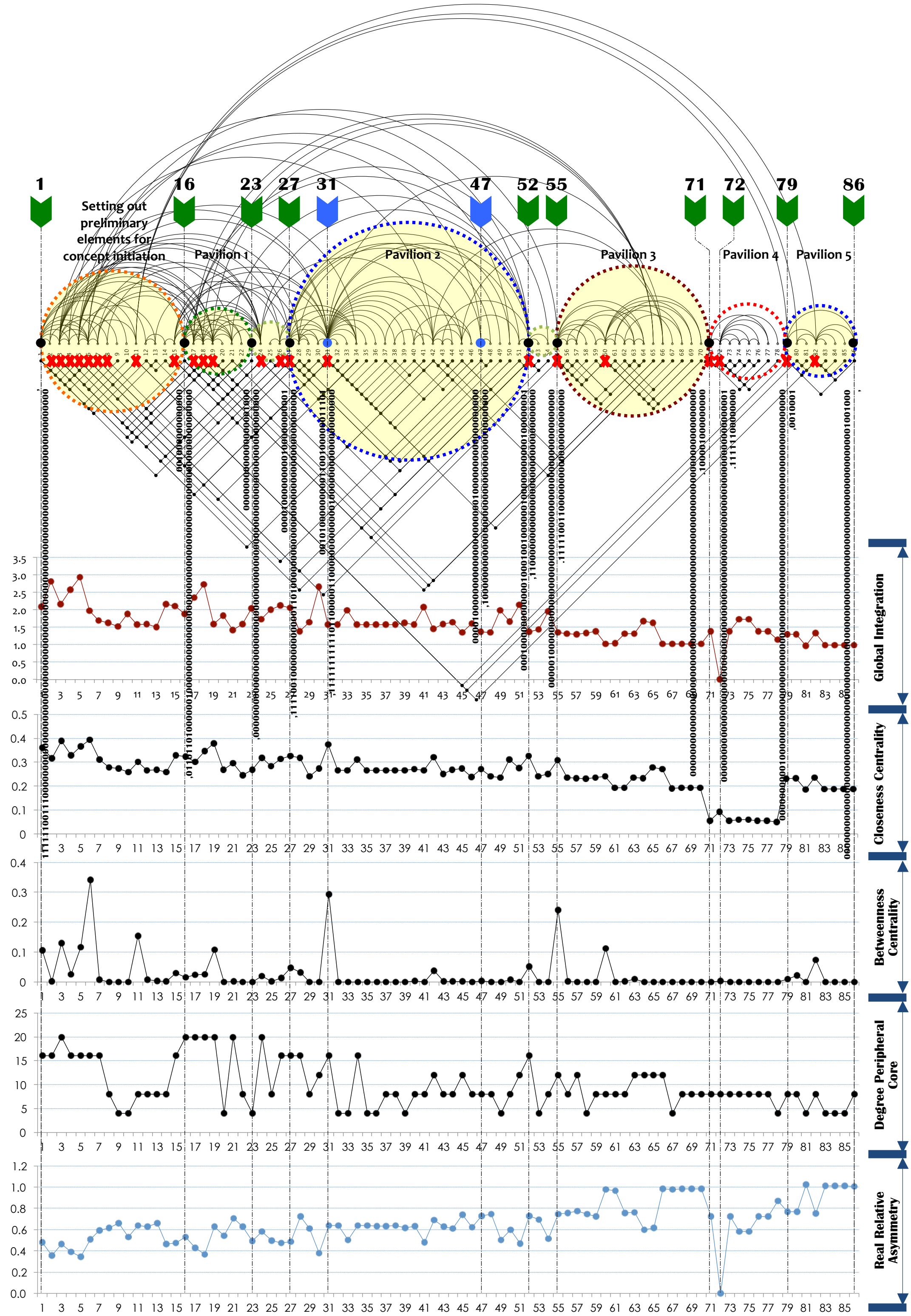


Figure 6.9 Network analysis for *concatenated* relations (Case Study 1, Designer 1)

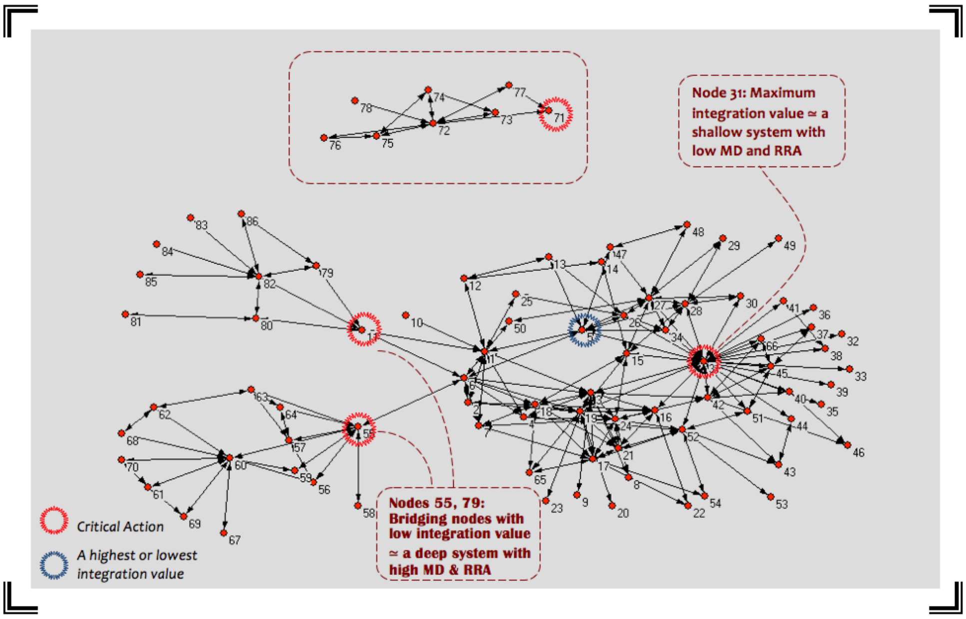


Figure 6.10 Distribution of the strength of nodes in the linkograph (Case Study 1, Designer 1)

Table 6.2 All the quantitative measurements for the linkograph protocol (Case Study 1, Designer 1)

#	Undirected Measurements								Directed Measurements					
	Closeness Centrality	Betweenness Centrality	Integration	Real Relative Asymmetry RRA	Degree Peripheral Core	T-complexity Concatenated strings	T-entropy Concatenated strings	T-information Con. Concatenated strings	Integration – Back Relations	Closeness Centrality – Back Relations	Betweenness Centrality – Back Relations	T-complex Back strings	T-entropy Back strings	T-information Back strings
1	0.36	0.11	2.09	0.48	16.00	11.40	0.41	35.54	0	0	0	0.00	0.00	2.09
2	0.32	0.00	2.81	0.36	16.00	10.09	0.34	29.64	0	1	0	1.00	1.42	2.84
3	0.39	0.13	2.15	0.46	20.00	14.08	0.56	48.54	0.21	0.67	0	2.00	1.36	4.08
4	0.33	0.03	2.57	0.39	16.00	10.13	0.34	29.83	1.00	0.75	0	2.00	1.02	4.08
5	0.37	0.12	2.92	0.34	16.00	11.91	0.44	37.91	0.70	0.57	0	3.00	1.17	5.84
6	0.39	0.34	1.98	0.51	16.00	12.58	0.47	41.15	0	1	0.25	2.58	0.84	5.04
7	0.31	0.01	1.69	0.59	16.00	10.98	0.39	33.61	1.27	0.6	0	4.00	1.16	8.09
8	0.28	0.00	1.62	0.62	8.00	8.98	0.29	24.94	0.69	0.44	0	3.32	0.81	6.51
9	0.27	0.00	1.52	0.66	4.00	8.29	0.25	22.15	0.81	0.44	0	3.58	0.79	7.10
10	0.26	0.00	1.89	0.53	4.00	8.27	0.25	22.08	1.10	0.47	0	4.17	0.85	8.52
11	0.30	0.15	1.57	0.64	8.00	11.13	0.39	34.30	1.33	0.5	0	4.32	0.81	8.92
12	0.27	0.01	1.59	0.63	8.00	8.77	0.28	24.11	1.31	0.48	0	4.46	0.77	9.28
13	0.27	0.00	1.51	0.66	8.00	9.93	0.33	28.96	0.91	0.38	0.01	4.58	0.74	9.62
14	0.26	0.00	2.15	0.46	8.00	9.17	0.30	25.74	0.87	0.35	0	4.58	0.69	9.62
15	0.33	0.03	2.10	0.48	16.00	10.81	0.38	32.84	0.64	0.27	0	4.81	0.68	10.24
16	0.32	0.02	1.87	0.53	20.00	11.39	0.41	35.51	0.94	0.36	0	4.70	0.62	9.94
17	0.30	0.02	2.34	0.43	20.00	14.04	0.56	48.38	1.08	0.38	0.01	5.32	0.69	11.75
18	0.35	0.03	2.73	0.37	20.00	14.46	0.58	50.49	2.48	0.57	0.19	6.39	0.84	15.19
19	0.38	0.11	1.60	0.63	20.00	13.46	0.52	45.44	2.52	0.56	0.08	7.32	0.97	18.48
20	0.27	0.00	1.84	0.54	4.00	8.07	0.24	21.29	1.20	0.37	0	5.25	0.58	11.52
21	0.30	0.00	1.42	0.70	20.00	11.13	0.39	34.30	1.81	0.48	0	6.91	0.81	16.98
22	0.25	0.00	1.60	0.63	8.00	9.02	0.29	25.12	1.10	0.34	0	5.91	0.62	13.58
23	0.27	0.00	2.05	0.49	4.00	8.00	0.24	21.04	1.34	0.38	0	5.32	0.51	11.75
24	0.32	0.02	1.72	0.58	20.00	14.45	0.58	50.45	2.72	0.55	0.08	9.17	1.07	25.74
25	0.28	0.00	2.00	0.50	8.00	7.93	0.24	20.77	1.35	0.37	0	4.64	0.39	9.78
26	0.31	0.01	2.12	0.47	16.00	12.73	0.48	41.84	1.13	0.32	0	6.46	0.59	15.42
27	0.32	0.05	2.06	0.49	16.00	14.79	0.60	52.22	1.56	0.39	0.03	6.32	0.55	14.95
28	0.32	0.03	1.38	0.72	16.00	13.25	0.51	44.39	1.57	0.39	0	6.46	0.55	15.42
29	0.24	0.00	1.63	0.61	8.00	8.86	0.28	24.45	1.06	0.3	0	6.34	0.52	15.01
30	0.27	0.00	2.66	0.38	12.00	8.81	0.28	24.24	1.10	0.3	0	6.39	0.51	15.19
31	0.37	0.29	1.57	0.64	16.00	17.98	0.80	69.38	2.97	0.55	0.16	9.32	0.85	26.37
32	0.27	0.00	1.57	0.64	4.00	7.78	0.23	20.20	1.45	0.36	0	5.95	0.43	13.73
33	0.27	0.00	1.99	0.50	4.00	7.75	0.23	20.10	1.49	0.36	0	6.00	0.42	13.88
34	0.31	0.00	1.57	0.64	16.00	11.31	0.40	35.14	2.02	0.43	0	8.39	0.66	22.58

35	0.27	0.00	1.57	0.64	4.00	7.70	0.23	19.89	1.57	0.37	0	6.00	0.40	13.88
36	0.27	0.00	1.58	0.63	4.00	7.67	0.23	19.79	1.61	0.37	0	6.13	0.40	14.31
37	0.27	0.00	1.58	0.63	8.00	8.39	0.26	22.58	1.65	0.38	0	6.17	0.39	14.44
38	0.27	0.00	1.57	0.64	8.00	8.52	0.27	23.10	1.69	0.38	0	6.13	0.38	14.31
39	0.27	0.00	1.62	0.62	4.00	7.58	0.22	19.46	1.73	0.38	0	6.00	0.36	13.88
40	0.27	0.00	1.58	0.63	8.00	9.36	0.30	26.52	1.77	0.38	0	6.17	0.36	14.44
41	0.27	0.00	2.07	0.48	8.00	8.52	0.27	23.10	1.84	0.39	0	7.17	0.44	17.92
42	0.32	0.04	1.45	0.69	12.00	12.39	0.46	40.22	2.54	0.46	0.01	8.00	0.50	21.04
43	0.25	0.00	1.59	0.63	8.00	10.13	0.34	29.83	1.42	0.32	0	6.39	0.35	15.19
44	0.27	0.00	1.64	0.61	8.00	8.43	0.26	22.71	1.94	0.39	0.01	7.04	0.40	17.47
45	0.27	0.00	1.35	0.74	12.00	10.39	0.36	30.98	2.10	0.41	0	8.17	0.48	21.70
46	0.24	0.00	1.62	0.62	8.00	8.36	0.26	22.44	1.51	0.33	0	7.32	0.40	18.48
47	0.27	0.00	1.37	0.73	8.00	9.29	0.30	26.22	1.65	0.35	0	7.32	0.39	18.48
48	0.24	0.00	1.34	0.75	8.00	8.29	0.25	22.15	1.52	0.33	0	7.25	0.38	18.21
49	0.24	0.00	1.99	0.50	4.00	7.25	0.21	18.21	1.48	0.32	0	6.39	0.31	15.19
50	0.31	0.01	1.66	0.60	8.00	8.21	0.25	21.85	1.98	0.38	0	6.52	0.31	15.64
51	0.28	0.00	2.13	0.47	12.00	9.13	0.29	25.57	2.02	0.39	0	7.17	0.35	17.92
52	0.32	0.05	1.37	0.73	16.00	13.63	0.53	46.29	2.81	0.46	0.04	10.81	0.63	32.84
53	0.24	0.00	1.44	0.69	4.00	8.09	0.25	21.38	1.55	0.32	0	6.70	0.31	16.25
54	0.25	0.00	1.95	0.51	8.00	9.04	0.29	25.22	1.72	0.34	0	7.09	0.33	17.63
55	0.31	0.24	1.34	0.75	12.00	11.69	0.42	36.91	1.52	0.31	0	6.61	0.29	15.95
56	0.24	0.00	1.32	0.76	8.00	9.34	0.30	26.45	1.07	0.24	0	6.78	0.30	16.53
57	0.23	0.00	1.29	0.77	12.00	10.11	0.34	29.74	1.10	0.25	0	7.37	0.33	18.64
58	0.23	0.00	1.34	0.75	4.00	7.86	0.24	20.49	1.11	0.25	0	6.83	0.29	16.72
59	0.24	0.00	1.38	0.72	8.00	8.34	0.26	22.37	1.13	0.25	0	6.81	0.28	16.63
60	0.24	0.11	1.02	0.98	8.00	12.09	0.45	38.77	1.17	0.25	0	7.83	0.34	20.40
61	0.19	0.00	1.03	0.97	8.00	10.09	0.34	29.64	0.89	0.2	0	6.91	0.28	16.98
62	0.19	0.00	1.32	0.76	8.00	10.25	0.35	30.35	0.91	0.21	0	6.91	0.27	16.98
63	0.23	0.01	1.31	0.76	12.00	11.11	0.39	34.20	1.22	0.26	0.02	8.81	0.38	24.24
64	0.23	0.00	1.67	0.60	12.00	10.11	0.34	29.74	1.24	0.26	0	8.78	0.38	24.14
65	0.28	0.00	1.62	0.62	12.00	9.63	0.32	27.67	1.78	0.33	0	8.11	0.33	21.46
66	0.27	0.00	1.02	0.98	12.00	9.39	0.31	26.67	1.89	0.35	0	8.39	0.34	22.58
67	0.19	0.00	1.02	0.98	4.00	7.91	0.24	20.68	0.96	0.21	0	6.98	0.26	17.23
68	0.19	0.00	1.02	0.98	8.00	9.25	0.30	26.06	0.98	0.21	0	7.91	0.30	20.68
69	0.19	0.00	1.02	0.98	8.00	9.17	0.30	25.74	0.99	0.21	0	8.00	0.30	21.04
70	0.19	0.00	1.02	0.98	8.00	9.09	0.29	25.39	1.01	0.22	0	7.98	0.30	20.95
71	0.05	0.00	1.38	0.73	8.00	9.32	0.30	26.37	0	0	0	6.15	0.20	14.37
72	0.09	0.00	0.00	0.00	8.00	10.98	0.39	33.61	0	0.03	0	7.15	0.25	17.85
73	0.05	0.00	1.38	0.73	8.00	9.29	0.30	26.22	0.21	0.03	0	7.17	0.25	17.92
74	0.06	0.00	1.72	0.58	8.00	9.17	0.30	25.74	1.00	0.04	0	7.75	0.27	20.10
75	0.06	0.00	1.72	0.58	8.00	10.27	0.35	30.43	1.06	0.04	0	8.17	0.29	21.70
76	0.05	0.00	1.38	0.73	8.00	9.27	0.30	26.14	1.16	0.05	0	8.17	0.29	21.70
77	0.05	0.00	1.38	0.73	8.00	8.91	0.28	24.65	1.27	0.05	0	7.81	0.26	20.32
78	0.05	0.00	1.15	0.87	4.00	8.17	0.25	21.70	1.15	0.06	0	7.17	0.23	17.92
79	0.23	0.01	1.30	0.77	8.00	10.11	0.34	29.74	1.17	0.22	0	7.09	0.22	17.63
80	0.23	0.02	1.31	0.77	8.00	9.61	0.32	27.58	1.19	0.22	0	7.11	0.22	17.70
81	0.19	0.00	0.97	1.03	4.00	8.39	0.26	22.58	0.92	0.18	0	7.32	0.23	18.48
82	0.24	0.07	1.33	0.75	8.00	11.39	0.41	35.49	1.24	0.22	0	9.04	0.31	25.22
83	0.19	0.00	0.99	1.01	4.00	8.39	0.26	22.58	0.95	0.18	0	7.36	0.22	18.61
84	0.19	0.00	0.99	1.01	4.00	8.39	0.26	22.58	0.96	0.18	0	7.36	0.22	18.61
85	0.19	0.00	0.99	1.01	4.00	8.39	0.26	22.58	0.97	0.19	0	7.39	0.22	18.74
86	0.19	0.00	0.99	1.01	8.00	8.91	0.28	24.65	0.99	0.19	0	7.91	0.24	20.68

Switching medium node

Critical actions and creative insight

In the following experimental cases, we look at three elementary factors distinguishing the design process of each architect that accord with the goal of empirical work. Our aim in this taxonomy is to reveal the implications of an unstructured design brief on the structure of reasoning and formation of novel concepts in order to investigate the research questions for this dissertation. The three elements are:

- Description of the early phase of concept initiation: *how does the first concept evolve?*
- Identification of the context beyond the emergence of creative insights: *in relation to the preceding one or not?*
- Identification of modes of reasoning from the emerging patterns in linkography: *rational or non-rational mode?*

6.4 Designer 2 – Case Study 1 of *Expo Pavilion Design*

6.4.1 Description of Concept Initiation

This architect began the process by proposing a variety of conceptual ideas to express the diversity of society and life in the UK, the country the pavilion represents in Expo Shanghai 2010. The concept revolved around diversity in a 'multi-ethnic, multicultural and multifaceted place and society'. A variety of conceptual artefacts were represented in this initial phase and were quite independent in their architectural treatment; each reflected a unique idea. Sketching episodes were consequently distinguished from *following* or *preceding* ideas. Rhythm of transition from one concept to the other was quick and spontaneous, and the thinking process reflected an insightful approach.

The architectural parti of the first concept (sketch 1-1) was for a 'user-generated sound disorder' pavilion, taking the form of typical English town. The architect mimicked London's riots in the summer 2011, which sparked youth in some other British cities. This concept presents the complexity of Britain, of a diverse, historical, problematic, economic, industrial, leadership society that is simplified in a few actions of protestors smashing some building façades to express their outraged feelings.

The second concept (sketch 1-2) presented the 'empire' in history, science and industry. Some keywords were outlined in a mind map and recalled in the following stages of design. The third concept (sketch 1-3) was the 'empty box: UK is what you make it'. This was meant to allow the users to build their own image about UK in an empty box using different piles of materials and to express the 'eccentricity' of Britain with the image of UK to keep evolving overtime.

The fourth concept (sketch 1-4) presented the 'sports day event'; another aspect to define a new UK where sport became a means of expression of popularly taking part in the British society. The concept is extended to mix sports with entertainment by creating the 'uphill cheese throwing' event. The fifth concept (sketch 1-6) presented the 'chemical plant' – a composition of geometric shapes that showed an advanced aspect of UK in scientific research and technology. Finally, the sixth concept (sketch 1-8) was a model for a 'roulette wheel' to show the entertainment side in the society. All these conceptual elements represented an 'image of the UK' from the architect's point of view.

The abstracted concepts were gathered in one congregated site-plan pavilion (sketch 2-1). This sketching medium reflected the convergent thinking in the designer's mind. This was explained by the architect in his retrospective comments as an attempt to capture Britain as 'a multifaceted place' in one building. Some keywords were elaborated and considered seeds of the conceptual image of UK. This conceptual initiation phase included: 'different characteristics of Britain', 'contemporary Britain', 'eccentricity', 'imperialism', 'village effect', and 'galleries, fairs, booths'. Figure 6.11 shows snapshots of the interim sketches and final product.

The whole congregation was elaborated in sketch (3-1) and the conceptual forms had taken a slightly different configuration; the 'empty box' was in the centre of the site-plan surrounded by the other pavilions: the 'user-generated sound disorder of London's riot', 'UK empire', the 'chemical plant', and the 'uphill sports event'. The site was covered with a blanket of different forms of *landscape*, *greenery*, *trees* and *shrubs* and a *pond*.

The architect ended this final representation by stating the main keywords of UK pavilion to include the following principles (1) Every visitor must interact with the empty box, (2) They can use any of the resources, (3) They can make an image, (4) They can make a visitor's box, which evolves overtime. At the end of the expo, it will show the visitor's experience in the box.

6.4.2 Description and Qualitative Analysis: Identification of Critical Creative Actions

The early stage of concept initiation reflects divergent insightful thinking process, paving the way for a variety of syntheses and conceptual hybridisation between the conceptual elements. This in turn has increased the probability of designing several solutions along the process. A paradigm shift occurred in the transition from the middle to the final stage that led to exceptional ideas along the process. The decision was made to centre the empty box as the prime element in the congregation. The remaining concepts were considered supplementary, each representing the UK image in the final product. However, the architectural forms of the concepts remained similar and to their definitions in the preceding phases. Concepts were designed in the final stage based on the former predefined ideas and the final product did not come up with any novel unprecedented designs.

Nevertheless, the variations to formulate the primacy of concept fluctuate throughout the process. The dependency relations between the design episodes are transcribed and coded to construct the linkograph.[70] Reading the linkograph of this process is characterised by the long *back*- and *forelinking*, divergence and convergence zones. Our aim in this section is to deduce the implications of the relation between the contents of interim artefacts and the structure of reasoning. Identification of critical actions and creative insights is described as follows:

First, after reading the design brief at node 1, a group of conceptual elements of the 'user-generated sound disorder', 'empty box', 'sports day – uphill cheese throwing', 'chemical plant', 'roulette wheel' pavilions emerged at nodes 2, 6, 9, 11 and 14 respectively. Although those concepts express the image of the UK, they have no relation to any keywords in the description of the design brief. However, the architect stated at node 3 that the aim of that earlier stage was to reflect as many diverse ideas as possible: 'I am taking from the brief to make as different ideas and sketches as possible.'

Those key concepts shifted the flow of sketching from one episode to another. Defying the prevailing concept, each action framed a new solution in relation to the whole configuration. All reflect the lateral transformation from one state to another to explore different ideas. At node 16, convergence action took place in the design discourse to congregate the preceding conceptual ideas in one configuration. This action reflects the incremental mode of reasoning that directed the following designing actions in a constructive way until the designing episode (sketch 2-1) ends.

At node 25, the final product is designed for sketch (3-1). A new 3-D perspective is dependent on building synthesis with the preceding sketch (2-1) and with the conceptual elements. This node reflects the multiple exchanges of information and ideas with the preceding sketches creating back- and forelinking. However, node 16 remains the prime bridging point of convergence that directs the actions of design and synthesis in this medium. Node 25 resembles advanced incremental action. Nevertheless the decision to centre the 'empty box' pavilion in the middle of the congregation distinguishes this sketching episode (3-1) from what was designed earlier at node 16 (sketch 2-1).

Figure 6.12 illustrates chronological generation of the concepts throughout the design process. Figure 6.13 is the annotation of sketching episodes and contents. In Figure 6.14 critical actions and switching nodes between every two media are demarcated over the linkograph. In Figure 6.15 the linkograph is overlaid with a diagrammatic study of the design process. And Figure 6.16 presents the synthesis phases, the convergence zone and transformation of concepts.

6.4.3 Correlation with Quantitative Measurements

First, we check the transitional nodes that are placed at the switching moments from one sketching medium to another: 2, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16 and 25. Further, this study includes the emergence of creative actions 2, 6, 8, 9, 11, 14, 16 and 25, which have commonly occurred while switching media and shifting from one sketch to another. Transitional nodes are considered creative actions in this discourse. This investigation also includes those nodes that have delivered significant integration and/or t-code measures, either 'high' or 'low' values.

- Node 16 delivers the highest integration value in the whole configuration linkograph, the most highly connected in the system, which also delivers the maximum t-code measures, diversified with relations. It is a transitional moment between two media sketches; displacement of exchanging information.
- Node 18 delivers the lowest degree of integration and the least connected.
- Node 21 delivers the lowest t-code measures. It is neither transitional nor considered as creative action.

[70] Detailed *transcription* and *coding* analyses are given in Appendix 6.2.

Identification of the significant actions in this design process is first made from the qualitative judgements of interim artefacts that represent the creative critical pivots for the development and transformation of the concept from one state of design to another. The following descriptions are based on the integrative model correlating qualitative and quantitative analyses to acquire information from the linkograph. This associates the contents of design (interim products) with the quantification of the structure of linkograph networks. Table 6.3 estimates connectivity values for the transitional nodes (located while switching from one sketching medium) and critical nodes (that achieve the highest or the lowest degrees of integration or t-code measures). Table 6.4 shows detailed measurements for the linkograph of this design process.

Starting with node 2, the first scribble of sketch SK(1-1) after reading the design brief is a controversial idea that represents London's riots of 2011, entitled 'user-generated sound disorder', which not every British person would agree as representing the image of the UK. However, the idea was recalled thereafter at nodes 16, in the congregational layout design at sketch SK(2-1), and at node 29 while designing the final design product of the whole process at sketch SK(3-1). This node is transitional between both media of design brief and sketch SK(1-1). The concept has grown in the architect's mind while designing the rest of the artefacts through the process and thus is considered a creative hinge or critical action in the whole discourse.

This entry of 'user-generated sound disorder' to convey emotions or anger like London's riots[71] is an intelligent expression with an aim to accommodate the visitors with the pavilion space throughout various materials of exhibition. The node is linked with 1 backlink and 3 forelinks with a total connectivity of only 4 links. It delivers a very low integration value of 1.26 of a deeply structured network of relations. Concatenated strings of information deliver relatively low values in relation to the overall nodes: t-complexity 8.0 (taugs) and t-entropy 0.57 (bits/char). This node is paradoxical, in the sense that although it is an important insight into a creative idea, it is weakly linked, delivering low integration and t-code measures.

At node 6 there is another sketching episode, different from the sketched concept of node 2, a new idea shifting the flow of design and representing the image of the UK through the 'empty box' sketch SK(1-3). This idea was recalled three times at nodes 13, 16 and 26 to emphasise the concept all through the process, particularly at the convergence zone sketch SK(2-1). At node 26, this action took a major turn in the evolution of concept, being centred on the site-layout as the prime space of the pavilion. It is a creative hinge, transitional between two media sketches SK(1-2) and SK(1-3). It is weakly linked with only 1 backlink and 3 forelinks of a total 4 connectivity links, delivering relatively a low integration value of 2.06. The created network is relative with median mean depth and real relative asymmetry. Concatenated strings of information deliver relatively low measures: t-complexity 8.46 (taugs) and t-entropy 0.62 (bits/char). Like node 2, it is paradoxical since it is an insight into a creative idea, it is weakly linked and delivers median integration value and t-code measures.

At node 8, a keyword is added to sketch SK(1-3) where the concept of 'eccentricity' has emerged and summing up the conceptual elements. This idea was advocated as a response to the definition of 'diverse Britain'. This node is weakly linked with 2 backlinks only, with the preceding idea of the 'empty box' at node 7 since it was the motivation for 'eccentricity' to occur. It was listed in the key concepts at sketch SK(1-2) of node 5. It delivers low integration value of 1.35 of a deeply structured network of relations. Concatenated strings of information deliver relatively low values in relation to the overall nodes: t-complexity 7.86 (taugs) and t-entropy 0.55 (bits/char).

At node 9, another conceptual idea of SK(1-4) entitled the 'UK sports day, village life, uphill cheese throwing'. This idea was recalled four times at nodes 13, 14, 16, and 28: the designer listed the key elements of the pavilion parti at node 13, reused the entertainment concept to create the roulette wheel idea at node 14, and designed the congregational layout pavilion at node 16 sketch SK(2-1), which was then transferred (displaced) at node 28 sketch SK(3-1). This is linked with 1 backlink and 4 forelinks with a total connectivity of 5 links. It delivers a median integration value of 2.02 of a semi-structured system. Concatenated strings of information deliver relatively high values in relation to the overall nodes: t-complexity 10.17 (taugs) and t-entropy 0.81 (bits/char).

[71] By providing tools to build or to demolish and creating a space for people's reactions, the architect considers this mirrors an opportunity for rioters to turn their anger to possible arts instead of smashing real premises.

At node 11, another idea shifted the flow of design to a new state representing the UK's multicultural society, and science and technology of the 'chemical plant' sketch SK(1-6). It was recalled twice at node 13, sketch SK(1-7), and node 16, sketch SK(2-1), of the congregated layout. However, this idea was abandoned in the enhancement of final sketch SK(3-1). It thus represents a false 'aha!' event in this discourse, where the architect thought it could be an element for the pavilion but then withdrew the proposition. It is linked with 1 backlink and 2 forelinks with a total connectivity of 3 links. It delivers low integration value of 1.9 of deeply structured network of relations. Concatenated strings of information deliver relatively high values: t-complexity 8.39 (taugs) and t-entropy 0.61 (bits/char).

At node 14, a sketching episode represents another aspect of entertainment pertinent to British society titled 'roulette wheel.' This idea shifted the flow of design from the precedents to a new independent state. It was recalled at node 16 for the congregational pavilion sketch SK(2-1). It is linked with 2 backlinks and 2 forelinks with 4 links in total. It delivers low integration of 1.7 of a deeply structured network of relations. Concatenated strings of information deliver relatively high values: t-complexity 8.98 (taugs) and t-entropy 0.67 (bits/char).

At node 16, an important designing action of convergence occurred and had impact on the ongoing process. A congregational layout gathered the preceding conceptual elements in sketch SK(2-1); the emerging ideas of nodes 2, 5, 6, 9, 10, 11, 13 and 14 were recalled in creating one concept design. This decision continued till the final product of sketch SK(3-1) at node 25 onwards. Therefore, this node is a pivotal bridging node transferring the preceding ideas into the stage of finalisation. It is a switching node between sketches in two different media. It is the most connected in the whole system with 16 links (8 backlinks and 8 forelinks). It delivers the highest integration in the whole system with a value 3.46 of a very shallow network of relations. Concatenated strings of information for this node delivers the highest values of the overall nodes: t-complexity 11.46 (taugs) and t-entropy 0.97 (bits/char). This node is thus a creative hinge in the whole linkograph that shows a very strong correlation between integration and t-code measures.[72]

At node 25, the final product of sketch SK(3-1) was designed and proceeded until the ending node 36. The congregation of sketch SK(2-1) was displaced from sketch (2-1), developed and enhanced. In this sketching episode, the 'user-generated sound disorder', 'chemical plant' and 'roulette wheel' ideas were abandoned in this sketch SK(3-1) after being restored in sketch SK(2-1). Placing the 'empty box' pavilion in the centre of the site layout was emphatically decided, to allow visitors to represent their concept of the UK using piles of different materials.

This concept of 'interaction' responded back to the conceptual form of node 6; creating a long backlinking relation between both hunches. This is considered a reformation of the concept that was initiated at node 16 of the congregated sketch SK(2-1) where the 'empty box' was a peripheral feature like the other pavilions; 'user-generated sound disorder', 'sports day, cheese throwing game', and 'roulette wheel'. Landscape elements of woods, hills and greenery were added to this final concept to represent the nature and topology of the UK.

Achieving the concept of the final product at this stage depended on a sequence of designing actions and steps until the ending point at node 36. The architectural treatment of some parts in the sketch was divided up into a sequence of action and thus not every action is fully linked with the other vertices (including node 25) in the linkography protocol in which created a structured network. This node is linked with 1 backlink and 10 forelinks of connectivity giving 11 links in total. It delivers relatively high integration value of 2.94 of a shallow network of relations. Concatenated string of information for this node delivers the highest values of the overall nodes: t-complexity 9.46 (taugs) and t-entropy 0.73 (bits/char). This node is thus a significant creative hinge in the whole linkograph.

See Figure 6.17 Quantitative measures for 'concatenated' relations; Figure 6.18 Measures for 'backlink – directed' relations; Figure 6.19 Network analysis for 'concatenated' relations; and Figure 6.20 Distribution of the strength of nodes in the linkograph.

[72] The applicability of the correlation between depth measures and t-code sets of information is explained in Chapter 5.

6.4.4 Results and Discussion

The variety of reasoning is characterised by the *incremental* and *insightful* modes of thinking. From analysis of integrative descriptions for this design process, we conclude that the *convergence* mode of thinking activates the pyramidal hierarchical mode of reasoning while *divergence* is not hierarchical and might or might not reflect the transformative mode. For example, node 16 is a bridging point that has directed the following design actions in the sketching medium SK(2-1) to achieve the conceptual forms associated with the initial sets of elements. There are no transformative relations in this design stage between the actions that could have reflected new notions on the predesigned artefacts. On the contrary, every node is connected to node 16 as giving orders to the actions to proceed constituting a linear process.

However, in the concept initiation phase, it was decided to make the conceptual ideas as distinctive as possible from brainstorming and insight, changed in apparently counterintuitive ways that engender divergence in thinking. In this phase, divergence and rapid shifting from one conceptual idea to a different one enlarged the pool of ideas, which increased the possibilities of solutions in the design space rather than deepened it into a particular detailed solution; see the types of *transformation of ideas* (Goel, 1995). The insightful process can be distinguished through the following hypotheses:

1) If the sudden shift breaks out of a frame of reference, shifting the design into a new state, as a result of the preceding action(s) of the interim artefacts, this resulting insight constitutes the transformative relation between the contents and structure of reasoning in the design process.
2) However, if the sudden insight has no relation with the preceding actions, it is considered a gleam of thought that flashed suddenly in the subconscious s mind.

The subsequent stages of design reflect an intention to develop the concept by building syntheses between the conceptual elements in one congregational layout. They are executional phases of what was already preconceptualised and designed in the insightful phase.

In the synthesis phase, the probability of the sudden occurrence of mental insights is high due to the combination of different conceptual elements that might induce unpredicted ideas; however, the process did not show any sudden flashes compared to the early stage of initiation.

Node 16, the set-up point for sketch SK(2-1), is a pivotal action in the conceptualisation process that plays a vital role in the evolution of the final product. It retrieved information from the preceding actions and demonstrated the incremental mode of thinking. It demonstrates the reliability of results based on the integrative model since it delivered the most significant quantitative measurements in the whole linkograph: the most connected, the highest integration value and t-code sets of information.

The insightful process reflected an *analytical* phase where the architect intended to experiment with different ideas to create seeds of concept. The following stages, however, were not analytical but were *synthetically* built. The linkograph illustrates an insightful, impulsive phase at the first half where the system is shallow and few relations are linked, while in the second half it is more connected and dense (see Figures 6.13, 6.14 and 6.15).

Node 25 bridges ideas from the preceding sketching episode sketch SK(2-1) with sketch SK(3-1), and also links the earlier seeds of initiation with the present design. The linkograph shows long back/forelinking between the initiation and final stages. It illustrates an unpredicted, insightful network with few dependency links in the initiation of sketching episodes sketch SK(1-1), but changes to present a consistent network of incremental reasoning at the mid and final stages of sketches SK(2-1) and SK(3-1).

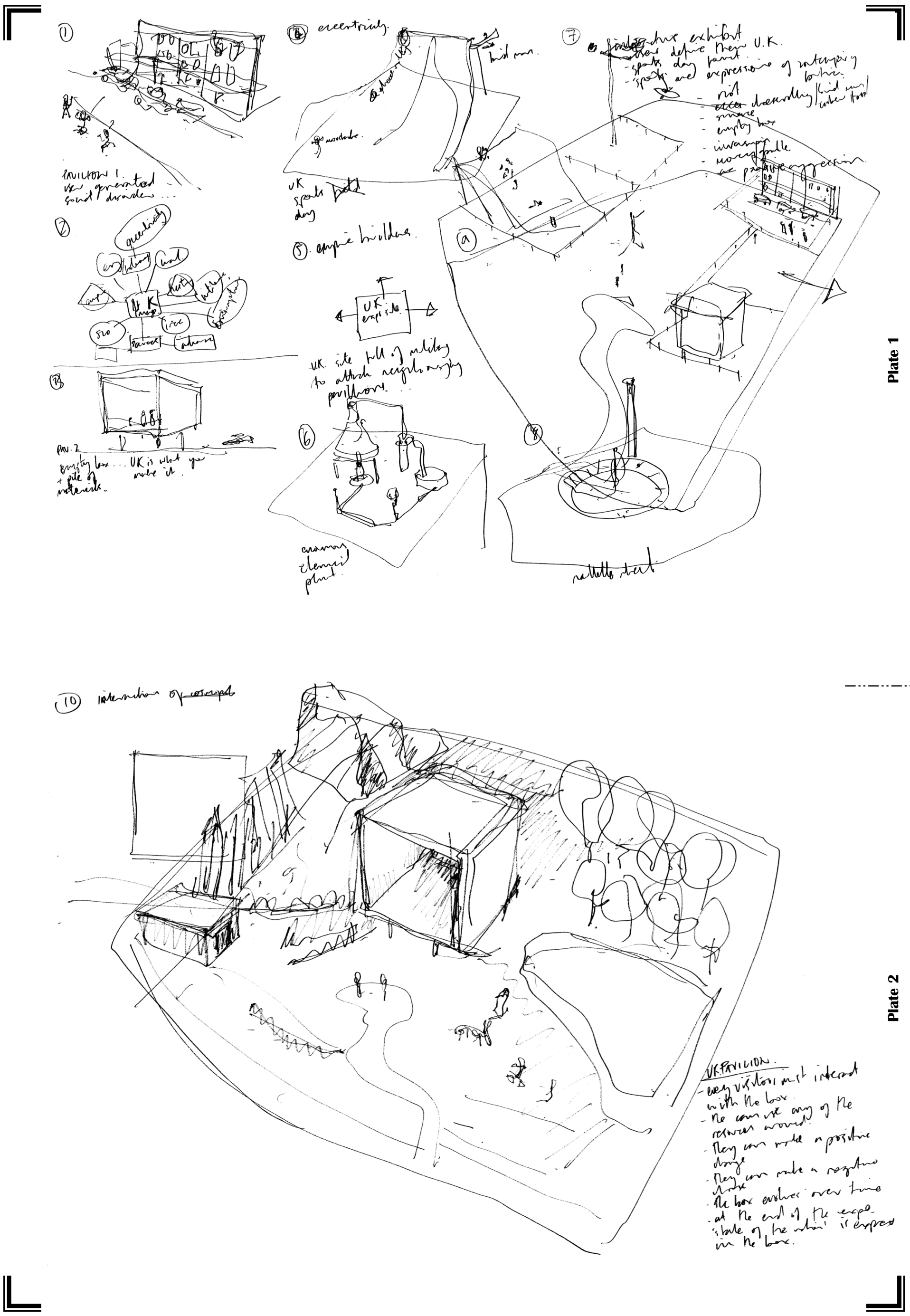


Figure 6.11 Illustration of sketches – The interim and final products of the design process (Case Study 1, Designer 2)

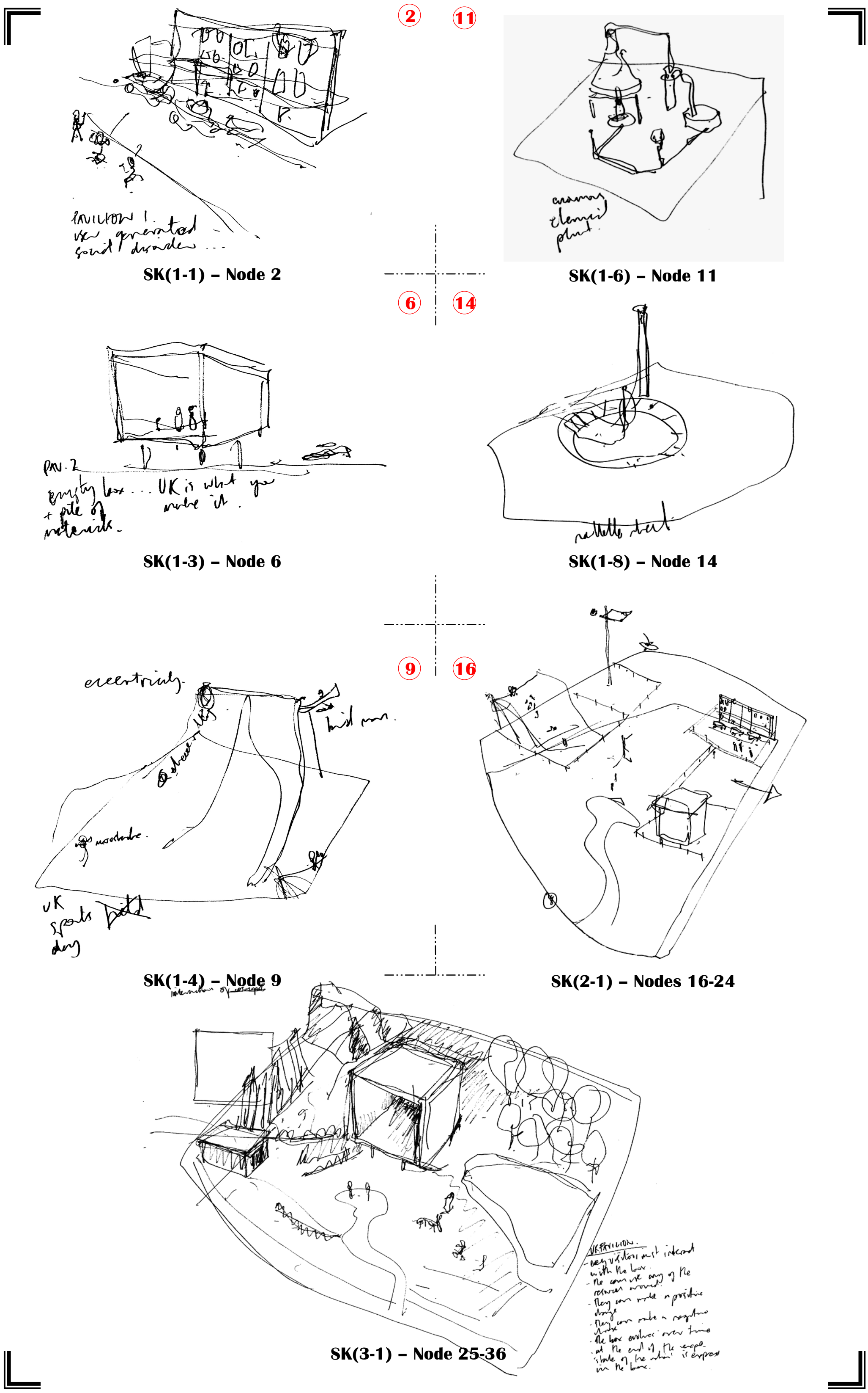


Figure 6.12 Chronological development of the conceptual and critical sketching episodes along the process

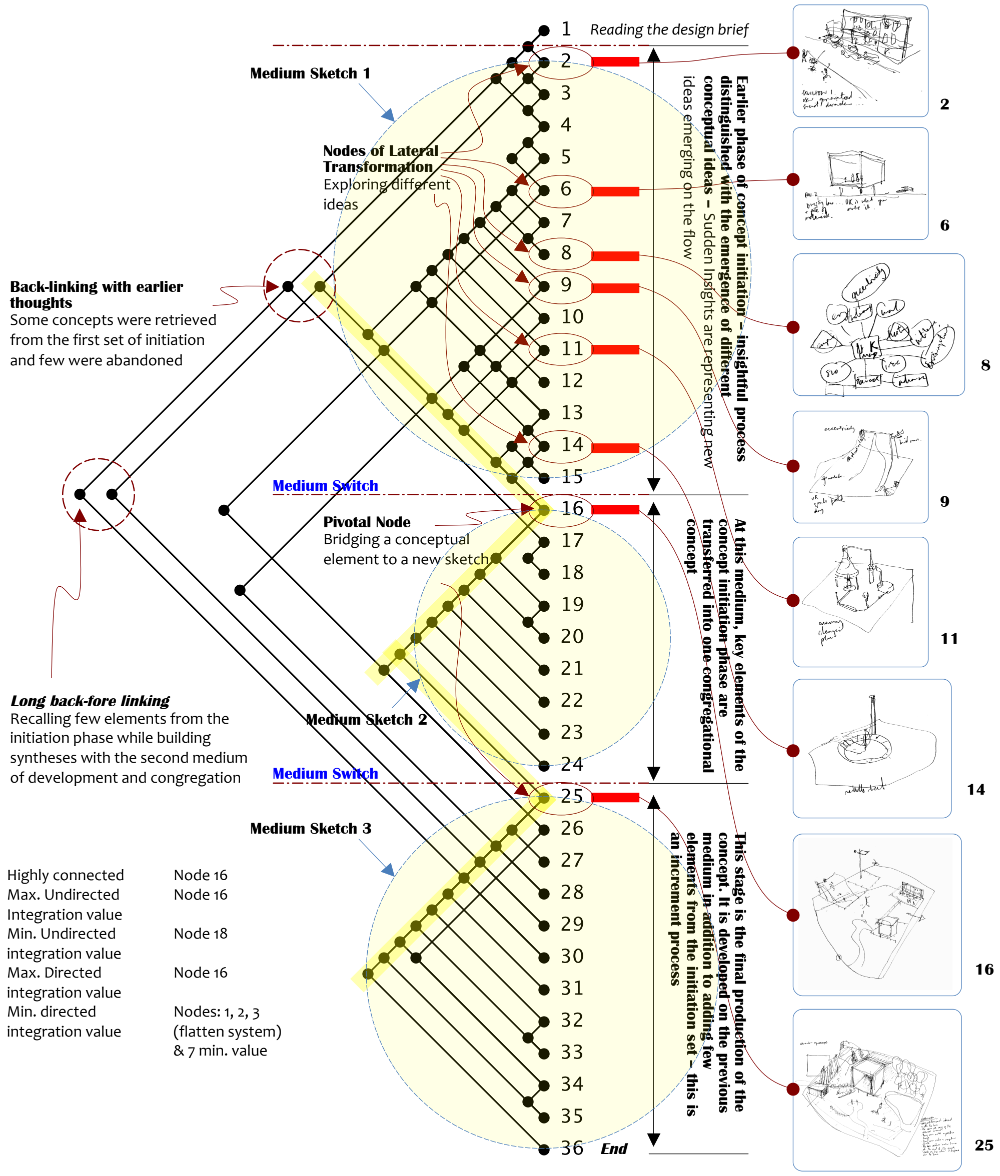


Figure 6.13 Annotation of creative actions and insights, sketching contents, concept transformations via back/forelinking and sketching exchanges

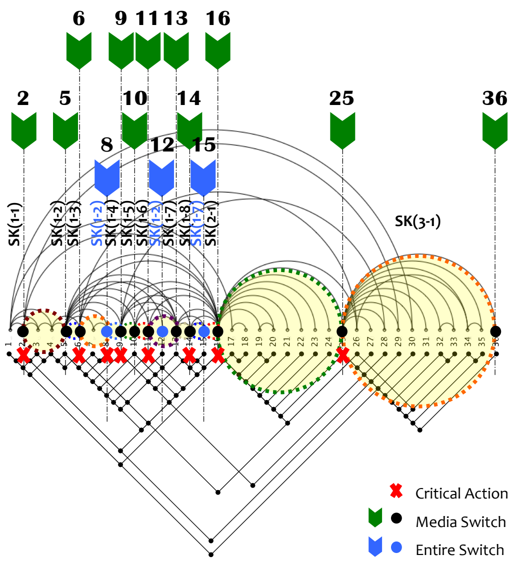


Figure 6.14 Linkography demarcated with the switching nodes and sudden insights (Case Study 1, Designer 2)

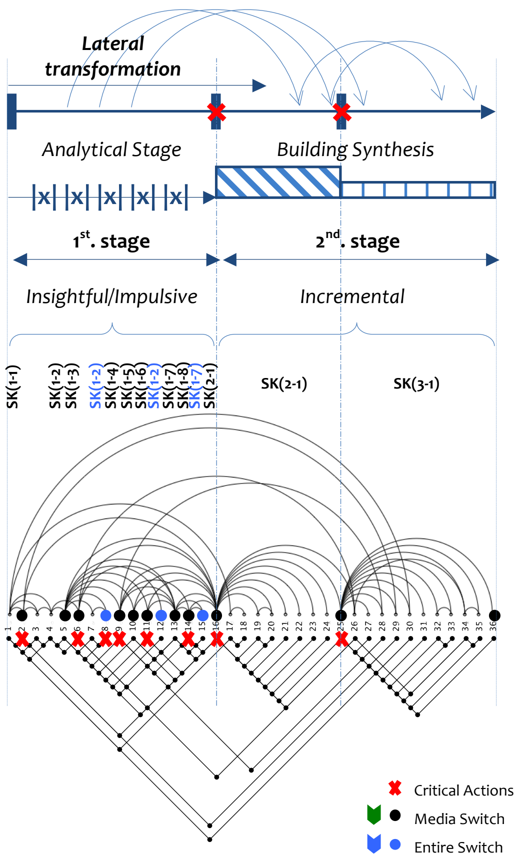


Figure 6.15 Linkography Protocol (Case Study 1, Designer 2)

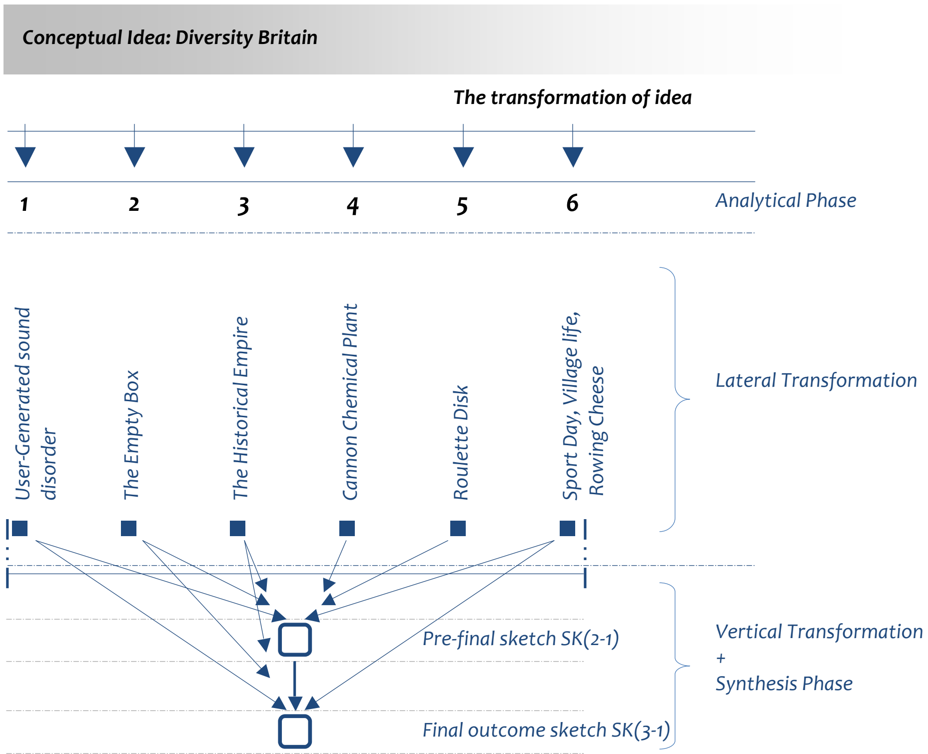


Figure 6.16 Stages of analysis and synthesis through the process of conceptual transformation via sketching episodes (Case Study 1, Designer 2)

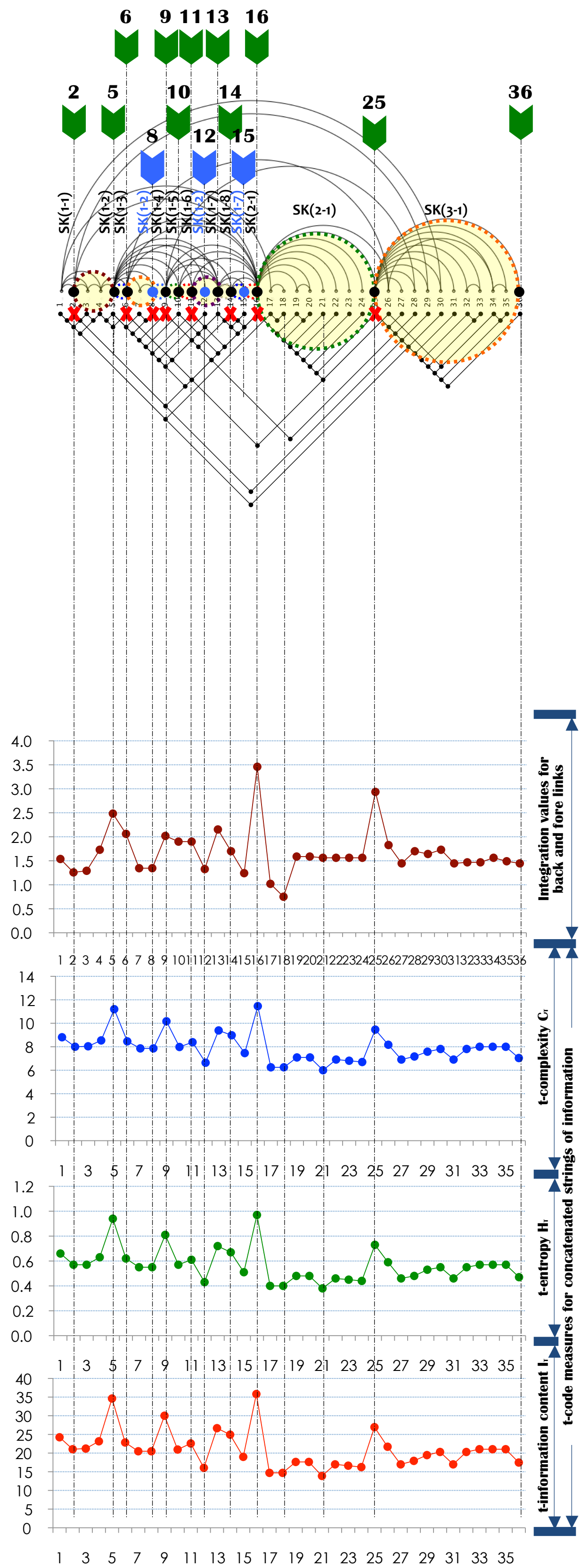


Figure 6.17 Quantitative measures for *concatenated* back/fore relations (Case Study 1, Designer 2)

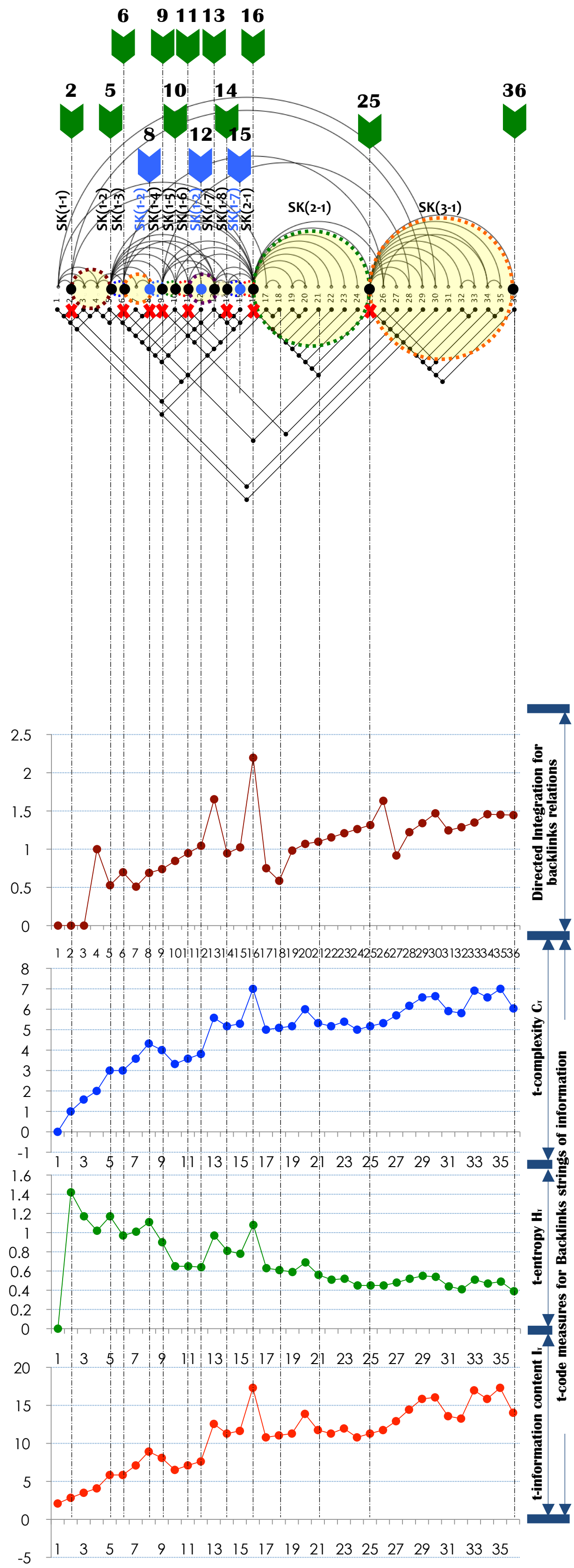


Figure 6.18 Quantitative measures for *backlink-directed* relations (Case Study 1, Designer 2)

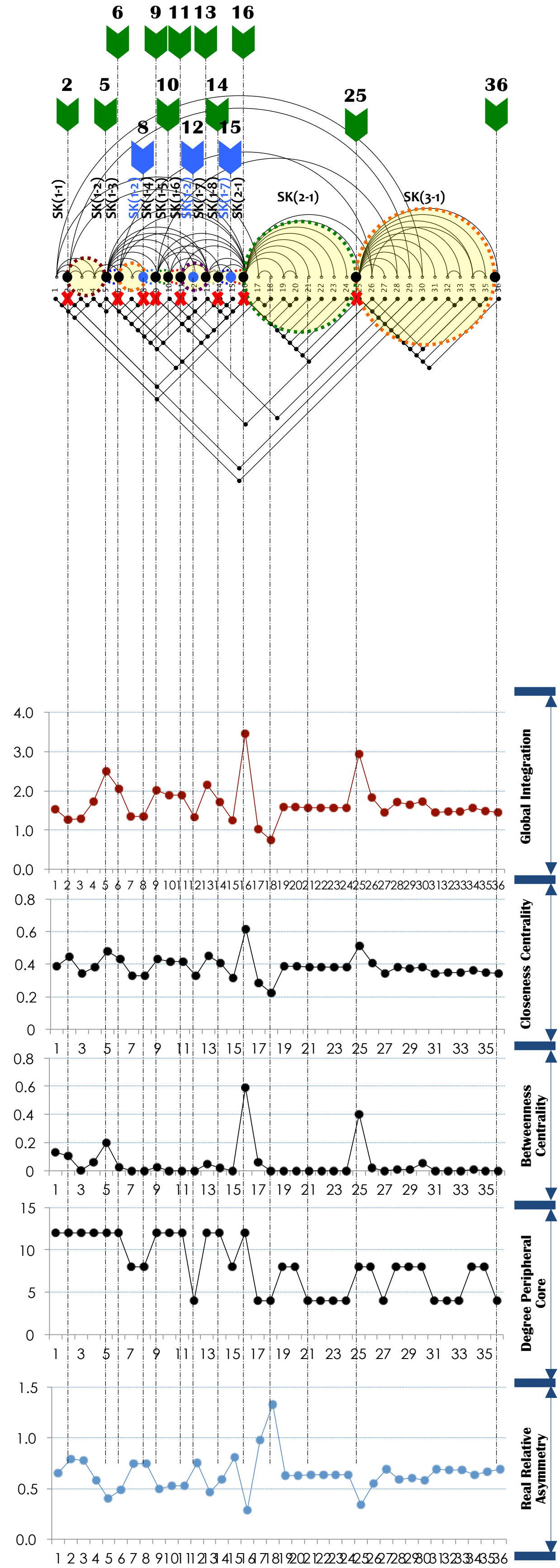


Figure 6.19 Network analysis for *concatenated* back/fore relations (Case Study 1, Designer 2)

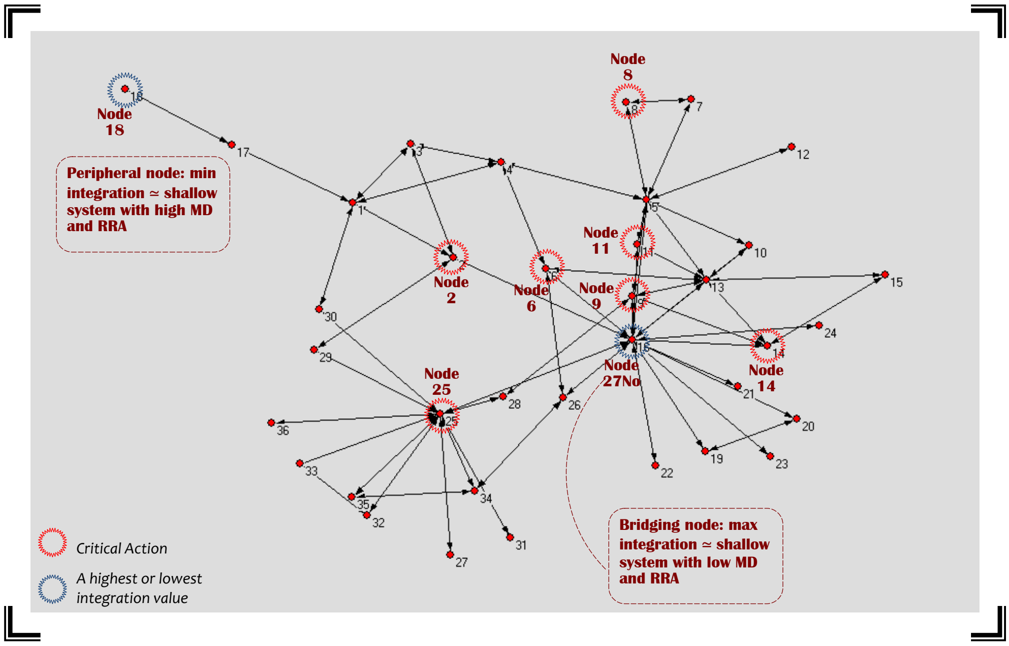


Figure 6.20 Distribution for the strength of connectivity of nodes in the linkograph (Case Study 1, Designer 2)

Table 6.3 Estimating connectivity values for the transitional nodes, switching media nodes, and significant nodes that achieve the highest or the lowest degrees of integration or t-code measures (Case Study 1, Designer 2)

Type	**Nodes**			
Switching nodes	2, 6, 8, 9, 10, 11, 12, 13, 14, 15, 16, 25, and 36			
Critical actions: sudden flashes transformation and paradigm shifts	2, 6, 8, 9, 11, 14, 16, and 25			
Significant Quantitative Values	**Nodes**			
Highest integration value	Node 18			
Lowest integration value	Node 16			
Highest t-codes measures	Node 16			
Lowest t-codes measures	Node 21			
Highest connectivity	Node 16			
Lowest connectivity	Nodes 12, 18, 21, 22, 23, 24, 27, 31, and 36 {with one link only}			
Estimation of Connectivity	**Nodes**	**Backlinks**	**Forelinks**	**∑ Links**
Node 2	{*bk* → 1 / *fore* → 3} = 4 links	1	3	4
Node 5	{bk → 1 / fore → 8} = 9 links	1	8	9
Node 6	{*bk* → 1 / *fore* → 3} = 4 links	1	3	4
Node 8	{*bk* → 2 / *fore* → 0} = 2 links	2	-	2
Node 9	{*bk* → 1 / *fore* → 4} = 5 links	1	4	5
Node 10	{*bk* → 1 / *fore* → 2} = 3 links	1	2	3
Node 11	{*bk* → 1 / *fore* → 2} = 3 links	1	2	3
Node 12	{*bk* → 1 / *fore* → 0} = 1 links	1	-	1
Node 13	{*bk* → 5 / *fore* → 3} = 8 links	5	3	8
Node 14	{*bk* → 2 / *fore* → 2} = 4 links	2	2	4
Node 15	{*bk* → 2 / *fore* → 0} = 2 links	2	-	2
Node 16	{*bk* → 8 / *fore* → 8} = 16 links	8	8	16
Node 18	{*bk* → 1 / *fore* → 0} = 1 links	1	-	1
Node 21	{*bk* → 1 / *fore* → 0} = 1 links	1	-	1
Node 25	{*bk* → 1 / *fore* → 10} = 11 links	1	10	11

Table 6.4 All the quantitative measurements for the linkograph protocol (Case Study 1, Designer 2)

#	Undirected Measurements								Directed Measurements					
	Closeness Centrality	Betweenness Centrality	Integration	Real Relative Asymmetry RRA	Degree Peripheral Core	T-complexity Concatenated strings	T-entropy Concatenated strings	T-info Concatenated strings	Integration – Back Relations	Closeness Centrality – Back Relations	Betweenness Centrality – Back Relations	T-complex Back strings C_T	T-entropy Back strings H_T	T-information Back strings I_T
1	0.39	0.13	1.54	0.65	12.00	8.81	0.66	24.24	0.00	0.00	0.00	0.00	0.00	2.09
2	0.44	0.11	1.26	0.79	12.00	8.00	0.57	21.04	0.00	1.00	0.00	1.00	1.42	2.84
3	0.34	0.00	1.29	0.77	12.00	8.04	0.57	21.21	0.00	1.00	0.00	1.58	1.17	3.50
4	0.38	0.06	1.73	0.58	12.00	8.54	0.63	23.16	1.00	0.75	0.00	2.00	1.02	4.08
5	0.48	0.20	2.48	0.40	12.00	11.20	0.94	34.62	0.53	0.50	0.00	3.00	1.17	5.84
6	0.43	0.03	2.06	0.49	12.00	8.46	0.62	22.84	0.70	0.50	0.00	3.00	0.97	5.84
7	0.33	0.00	1.35	0.74	8.00	7.86	0.55	20.49	0.51	0.38	0.00	3.58	1.01	7.10
8	0.33	0.00	1.35	0.74	8.00	7.86	0.55	20.49	0.69	0.41	0.00	4.32	1.11	8.92
9	0.43	0.03	2.02	0.50	12.00	10.17	0.81	30.01	0.74	0.40	0.00	4.00	0.90	8.09
10	0.42	0.00	1.90	0.53	12.00	7.98	0.57	20.95	0.85	0.41	0.00	3.32	0.65	6.51
11	0.42	0.00	1.90	0.53	12.00	8.39	0.61	22.58	0.95	0.42	0.00	3.58	0.65	7.10
12	0.33	0.00	1.33	0.75	4.00	6.64	0.43	16.05	1.04	0.42	0.00	3.81	0.64	7.62
13	0.45	0.05	2.15	0.46	12.00	9.39	0.72	26.67	1.65	0.52	0.10	5.58	0.97	12.56
14	0.41	0.02	1.70	0.59	12.00	8.98	0.67	24.94	0.95	0.37	0.00	5.17	0.81	11.29
15	0.32	0.00	1.24	0.81	8.00	7.46	0.51	18.99	1.02	0.38	0.00	5.29	0.78	11.64
16	0.61	0.59	3.46	0.29	12.00	11.46	0.97	35.82	2.20	0.68	0.22	7.00	1.08	17.31
17	0.29	0.06	1.02	0.98	4.00	6.25	0.40	14.70	0.75	0.30	0.00	5.00	0.63	10.79
18	0.22	0.00	0.75	1.33	4.00	6.25	0.40	14.70	0.59	0.24	0.00	5.09	0.61	11.05
19	0.39	0.00	1.59	0.63	8.00	7.09	0.48	17.63	0.98	0.38	0.00	5.17	0.59	11.29
20	0.39	0.00	1.59	0.63	8.00	7.09	0.48	17.63	1.07	0.40	0.00	6.00	0.69	13.88
21	0.38	0.00	1.56	0.64	4.00	6.00	0.38	13.88	1.10	0.39	0.00	5.32	0.56	11.75
22	0.38	0.00	1.56	0.64	4.00	6.91	0.46	16.98	1.15	0.40	0.00	5.17	0.51	11.29
23	0.38	0.00	1.56	0.64	4.00	6.81	0.45	16.63	1.21	0.40	0.00	5.39	0.52	11.96
24	0.38	0.00	1.56	0.64	4.00	6.70	0.44	16.25	1.26	0.40	0.00	5.00	0.45	10.79
25	0.51	0.40	2.94	0.34	8.00	9.46	0.73	26.95	1.32	0.41	0.00	5.17	0.45	11.29
26	0.41	0.02	1.83	0.55	8.00	8.17	0.59	21.70	1.63	0.42	0.00	5.32	0.45	11.75
27	0.34	0.00	1.45	0.69	4.00	6.91	0.46	16.98	0.92	0.30	0.00	5.70	0.48	12.92
28	0.38	0.01	1.70	0.59	8.00	7.17	0.48	17.92	1.22	0.34	0.00	6.17	0.52	14.44
29	0.37	0.01	1.64	0.61	8.00	7.58	0.53	19.46	1.34	0.35	0.02	6.58	0.55	15.85
30	0.38	0.05	1.73	0.58	8.00	7.81	0.55	20.30	1.47	0.37	0.03	6.64	0.54	16.05
31	0.34	0.00	1.45	0.69	4.00	6.91	0.46	16.98	1.25	0.33	0.00	5.91	0.44	13.58
32	0.35	0.00	1.47	0.68	4.00	7.81	0.55	20.30	1.29	0.33	0.00	5.81	0.41	13.26
33	0.35	0.00	1.47	0.68	4.00	8.00	0.57	21.04	1.35	0.34	0.00	6.91	0.51	16.98
34	0.36	0.01	1.56	0.64	8.00	8.00	0.57	21.04	1.46	0.35	0.01	6.58	0.47	15.85
35	0.35	0.00	1.49	0.67	8.00	8.00	0.57	21.04	1.45	0.35	0.00	7.00	0.49	17.31
36	0.34	0.00	1.45	0.69	4.00	7.04	0.47	17.47	1.45	0.34	0.00	6.04	0.39	14.03

Switching medium node
Critical actions and creative insight
Highest vs. lowest degree of integration or t-code measures

Our investigative approach throughout these case studies is based on setting up elements of description that accord with the objective of empirical work. Our aim for the adopted taxonomy of analysis is to reveal the context in which creative ideas occur and the implications of the sudden emergence of creative insights and paradigm shifts on the structure of reasoning in the design process in light of the emergent patterns of links and linkography protocol.

6.5 Designer 3 – Case Study 1 of *Expo Pavilion Design*

6.5.1 Description of Concept Initiation

The architect started the process by designing key conceptual elements that refer to the nature of his country, Egypt. This design process started with processing different analyses of the given site to build the project – an enclosed image with the design brief. Among the tasks that were analysed was measuring the scale of the site-layout and proportions in relation to the sketch drawing (using a scale ruler and finger tips). The architect aimed to analyse the orientation towards the 'north', ways to place 'landscape' elements, and the main 'entrance' of the site. Analysing the *morphology* of site led to generate generic concepts for the form and masses of the project, e.g. drawing some *axial* and *construction* lines, setting up *intersection* points, and considering the direction of the river passing across the northern direction.

Site analysis was extensively articulated in the concept initiation phase. A tracing sheet was placed over the site-plan (with the design brief) while some early notions were scribbled down to transfer the first hints of ideas into conceptual drawing of a zoning diagram for the main functional spaces of the pavilion.

Some of the landscape elements were influenced by the site-plan while setting up the design configuration; physical objects were measured to sense their real scale, such as the *peripheral service* roads. The *width* and *length* of the buildings' mass were assumed accordingly. The tendency to analyse the orientation of site aimed to utilise the possible advantages that comes from placing some functional zones towards that northern location of the river and prevailing winds.

A decision was thus made to exploit the 'outdoors northern view' and enrich the conceptual idea. This motivated the design to consider the concept of 'transparency' of a northern glazing façade, contrasted with an 'opaque' southern façade for the entrance. While reflecting an aesthetic value of contrast between transparency and opaqueness, the concept was extended further to resonate a philosophical idea to represent the eras *before* and *after* the 'Spring Revolution in Egypt 2011' and the transition phases. This idea has turned the form into a hybrid of soft and axial lines that represent 'oppression' versus 'optimism' and 'opaqueness' versus 'transparency'. Figure 6.21 illustrates the interim artefacts and final product of this design process.

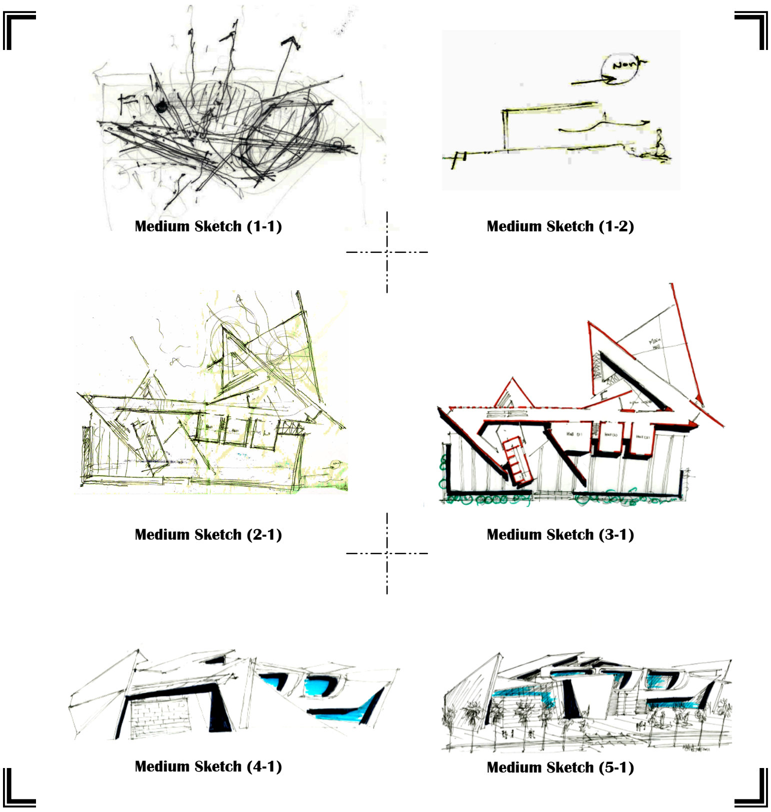


Figure 6.21 Illustration of sketches – The interim and final products of the design process (Case Study 1, Designer 3)

6.5.2 Description and Qualitative Analysis: Identification of Critical Creative Actions

The designing actions are centred on the concept of influencing the morphology of the given site with a projected synthesis of what the image of Egypt would be after the Spring Revolution. This had an implication for the evolution of significant ideas that took an *incremental* form of reasoning. Most of the actions were related and responsive to that concept. The process took a *linear* and *iterative* form of reasoning thereafter. The following description identifies the emergence of the critical and creative actions with emphasis on the implications of the structure of reasoning on the emergent solutions and interim artefacts.[73]

At node 13, the architect's verbalisation brought our attention to a sudden shifting action that would not have been thought of earlier in the design process. At node 14, a sudden idea shifted the design process to implement a different course of sketching actions with an aim to proceed the concept to more details. In a sudden moment of an 'aha' event, a conceptual idea was set up to design the *cross-section* responsive to the initial concept embedding 'natural lighting' of 'openness' and 'bright future' while creating a hierarchical theatrical space with glazing façade located towards the north in contrast to an enclosure of opaqueness to the south.

The flow of sketching before this sudden mental insight was about sketching some axial lines of analysis of the given site-plan. While creating cues of reflections with the sketch, the sudden hint occurred based on the personal idiosyncrasy of the architect transforming an abstract idea into a configuration of forms. The verbalisation at this action indicates that the sketch was from subconsciousness imagination based on *perceptive moment-in-action*:[74] 'I will leave myself to my subconscious imagination to draw and scribble some circles, arcs and lines.'

[73] Detailed *transcription* and *coding* analyses are found in Appendix 6.3.

[74] See Chapter 4 to view Tschimmel's interpretation of design as a perception-in-action (2010) and the proposition of coding the gradual transformation of mental imagery through sketching.

This action shows the dependency on the subconscious imagination to reflect an insight on the prevalent thinking flow; however, the attempt to achieve that concept was in fact based on some featured elements that were already set up in the preceding action. The sketching actions and sequential drawings starting from node 13 were based on the analyses of the given site-plan established in the preceding analytical phase, e.g. setting up construction lines and pivotal points of intersection with respect to the conceptual idea of openness towards the northern facade.

Decisions for the orientation of the main 'exhibition hall' on the 'transparent' façade, overlooking the 'outdoor' exhibition and communal area, or the 'opaque' entrance, were all made in relation to the preceding actions of the site-plan analysis in addition to the insight emerging at node 14. This tendency to distribute the configuration of forms and functional spaces to face the elongated river at northern side is a distinctive example of the *dependency* on site analysis. Merging *conceptual interpretation* and *site analysis* was associated with high-calibre sketching and imagination skills and the personal idiosyncrasy of the architect. The design form reflected the *centrifuge* of lines, shapes and 3-D forms that was only based on the architect's idiosyncratic treatment of geometries rather than the conceptual philosophy that can be represented through a variety of design configurations.

The sudden paradigm shift occurring at moment 14 extended the prevalent concept to explore further details instead of changing the whole design situation to a different state. We interpret this event as an *incremental* form of reasoning in that, although a mental insight occurred suddenly, it extended the concept to a vertical transformation to reframe the solution instead of restructure a different one.

It is stimulation in the brain that can be seen to occur due to the *synthesis* between two different intuitive thoughts: (1) the prevalent concept to reflect on the spring revolution and areas of transparency versus opaqueness; and (2) the architectural treatment of a hierarchical cross-section. This overlaps with the architect's imagination of the 'ambience'; how could the visitor experience the 'exhibition space', the association with 'outdoors area', and the 'optimistic' impression for the future after revolution from viewing the scene through the 'transparent' façade overlooking the 'greenery area' and the 'elongated river' (benefitting from the northern location). Figure 6.22 illustrates the sudden shift in switching from the site analysis study sketch SK(1-1) to the emergent concept for the *cross-section* drawing sketch SK(1-2).

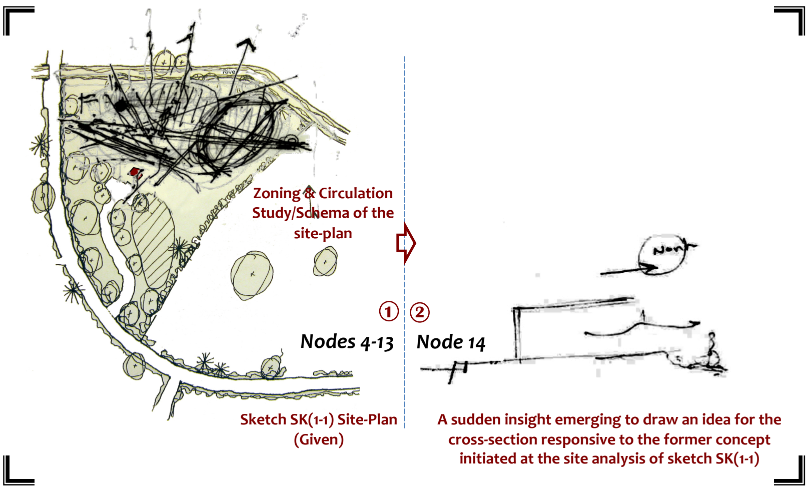


Figure 6.22 An occurrence of sudden creative insight switching from one sketching medium to another – the development of concept via two projections: plan and section (Case Study 1, Designer 3)

At node 15, a decision was made, emphasised and elaborated at nodes 17, 21 and 22, to convey the impression of 'suffering' versus 'optimistic' into the concept of 'opaque' versus 'transparency', e.g. the futuristic view towards the northern transparent façade and outdoors exhibition next to the green area and passing river. The idea was extended to include indirect 'natural lighting' to express the future into the exhibition hall. Those conceptual principles structured the solutions and emerging artefacts (drawings) through the following stages to preserve the concept.

At node 22, the designer decided to create a circulation route to link a group of exhibition halls together. Each hall represents a different era including a variety of 'exhibits', 'portraits and photography', and 'digital simulations'. The circulation path was divided into different lengths and proportions to show the rhythm of time associated with each era before and after the revolution. This intended to give an impression of gradual transformation towards the revolution of 25 January. At node 23, the architect decided to implement portraiture and photography to convey the state of art before and after the revolution.

At node 24, the design reflected the 'confliction' point that was translated into the intersection of 'centrifuged axial lines'. The main exhibition hall was located at the centre of the intersection. This was sketched in the diagrammatic illustration of sketch SK(1-1) – a circular form around that intersection point. The designer decided to put an end to the circulation tour by reaching a surprising conclusion represented by the futuristic outdoor exhibition. This is clarified at nodes 24 and 25 respectively: 'The whole circulation would lead to the form of the composition as a whole'.

Using lights to fall on the exhibits was meant to express certain moments of 'brightness' versus 'darkness' or looking towards the future to symbolise 'freedom'. These clarifications were reflected in the sketching episode of node 26.

A new sketching episode took place starting from node 27 and continuing until node 36. All the decisions that were made and sketched in the diagrammatic sketch SK(1-1) were transferred into a scaled architectural drawing in medium sketch SK(2-1) provided with precise measurements. This sketch included the main functional elements of the master plan: the 'main entrance', leading to the 'movement path', that links between the 'exhibition spaces' with different types of exhibits. This path ascends into different split-level spaces until reaching the main mass at its end. The main mass has a descending 'triangular ramp' towards the lower level, leading to the outdoors communal area. The execution of this scenario was divided into a sequence of actions of incremental reasoning that preserved the concept and reframed the original concept. The architect commented at node 36: 'We want to overcome every change and everything [that] causes withdrawal to the country' (i.e. undermines development).

Medium sketch SK(3-1) took place from nodes 37 to 50. In this sketch, the designer intended to redraw the master plan of sketch SK(2-1) into a fully detailed drawing with accurate measurements. This sketching session included setting up the 'structure elements', 'repetitive openings' and 'slight windows', 'light installations' and pertinent fittings, 'utilities' and 'circulation elements' (staircases, elevators, escalators), adding annotations, and labelling the exhibition halls.

At node 42, the concept was described by using expressive words to elaborate certain meanings, e.g. the 'deviation' path, 'edgy-transmission', 'overcoming withdrawals', 'penetration', 'solid' and 'hard' masses, 'revolution' and 'opaque' eras. See Appendix 6.3 for the transcription for each design segment.

At node 46, a platform (plateau) was drawn to surround the whole pavilion including an 'English court' access to the basement floor. Adding some landscape elements at node 47 to surround the plateau of mass, the concept symbolised the 'fertility' resulting from the Spring Revolution. Landscape elements took a modular pattern in contrast to the free spontaneous configuration of forms of the main masses. Finding their way through the different 'revolutionary' masses creates a 'fourth dimension' for visitors, who also get different experiences from passing through various elevations with 3-D forms, lighting, materials etc.

At node 48, the openings and windows were marked out in the master plan to show the *solids* and *voids* between masses. The master plan sketch SK(3-1) was then finalised and represented (black shadows) to assure the potentials of the form: 'The English court is to separate the exhibition zone and the outdoor area'.

Medium sketch SK(4-1) for the main façade was set up, starting from node 51 until 56. This was considered a creative leap in the development of the conceptual idea shifting from the 2-D master plan to a 3-D perspective of the front façade. This was considered a critical action directing the process drastically to explore a new dimension of design. The architect showed *high-calibre sketching skills* designing the forms and sketching the 3-D perspective *simultaneously* based on an *imaginative* picture in the mind. The design actions of this particular session represented the conceptual idea of revolutionary forms in 3-D masses. Some elements were described as 'overhead lighting', the 'straggling roof', 'masses have inclined and bended surfaces' (see the transcriptions in Appendix 6.3).

This has reinforced the dominance of concept that structured the production of every interim artefact in the following stage. Through two different sketching media; SK(4-1) and SK(5-1), the concept was emphasised and developed into details. An indication of stones and masonry work to reflect the vernacular nature of Egypt rendered the façade exterior cladding to support the connection to heritage.

At node 57, the sketch was refined again in a new sketching medium SK(5-1), resumed until node 62; the ending moment in the whole design process. The main construction lines of the new sketch were traced over the old one SK(4-1) but with more precision and accurate measurements. Figure 6.23 presents the transformation of concept via sketching the 3-D perspective of sketch SK(4-1) and its final development at sketch SK(5-1).

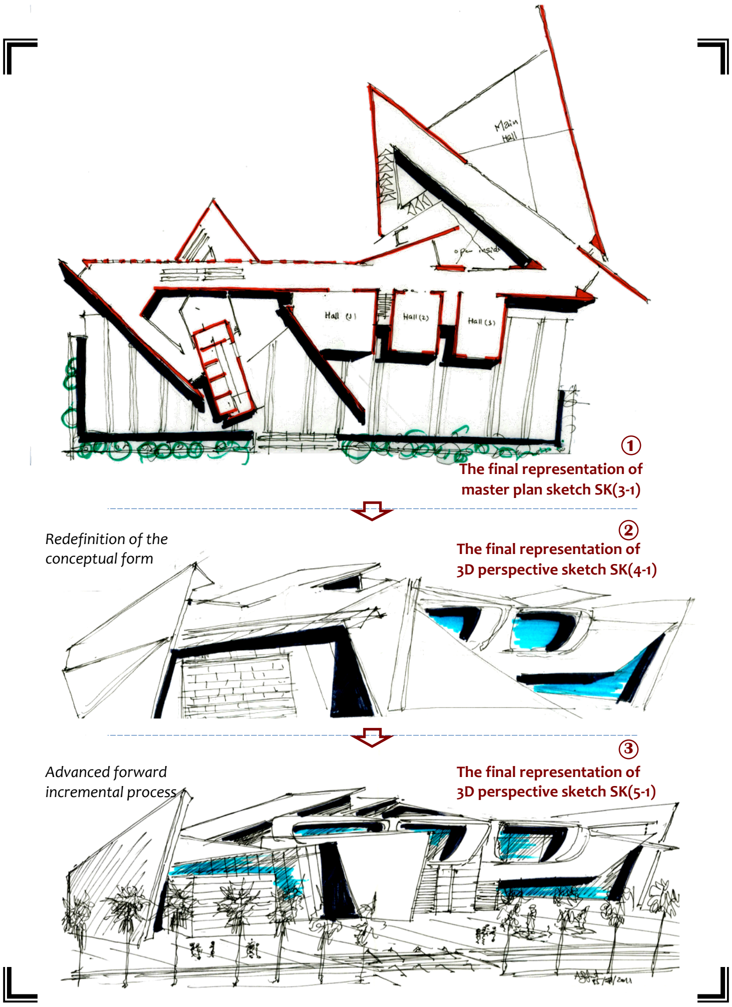


Figure 6.23 Transformation of concept through various projections from 2-D to 3-D drawings (Case Study 1, Designer 3)

6.5.3 Correlation with Quantitative Measurements

We start our investigation by inspecting the *transitional* nodes that are placed at the *switching moments* from one medium sketch to another: 4, 14, 15, 27, 37, 51 and 57. However, the locus of this correlation study focuses on investigating the structure of networks created at each creative action and creative insight that were already detected and explained through the qualitative descriptions on the contents of sketches and structure of reasoning.

Nodes 14 and 51 are considered critical creative actions in the whole design process. Node 14 is distinguished from the other actions due to the sudden insight occurring that led to extend the concept through several architectural treatments. Node 51, however, reflects a creative leap and competent sketching and imagination skills and performance by the architect. However, in the whole linkograph (after completion), the following nodes delivered significant results as follows:

- Node 27 delivers the maximum integration measure in the whole linkograph with value 2.87; then node 37 comes second with value 2.66. Both nodes are transitional switching media from one sketch to another.
- Node 4 is the most connected action in the linkograph with 20 links in total (3 *backlinks*; 17 *forelinks*). Node 37 comes second with 19 links in total (3 *backlinks*; 16 *forelinks*). Both nodes are highly connected creating a kind of 'semi-saturated' network on the local level.
- Node 19 delivers the minimum integrated action in the whole linkograph with value 1.09.
- Node 37 has the maximum t-code measures. The variety of arrangement of the character strings of codes is associated with the structured pattern of local network and also associated with the high connectivity within the linkograph.
- Node 41 has the lowest t-code measures in the whole linkograph.

At node 4, the first scribbles on the sketch were drawn SK(1-1) while tracing over the site-plan (the design brief). Reflecting site analysis, this sketching episode was recalled several times giving the maximum connectivity in the whole linkograph of 20 links (3 *backlinks* and 17 *forelinks*), though it delivers a median integration of 1.95 value and low mean depth and real relative asymmetry values on balance to the rest of nodes in the whole linkograph. Concatenated strings of information delivered high t-complexity 11.61 (taugs) and high t-entropy 0.58 (bits/char). This node however has delivered relatively high closeness centrality measure 0.37 and a maximum value of betweenness centrality 0.16 on the overall linkography measurements.

At node 14, a sudden mental insight occurred to design the cross-section drawing for a hierarchical space, a hybrid of 'transparency' and 'indirect lighting' for the exhibition halls versus 'opaqueness' representing the eras *before* and *after* the Spring Revolution, 2011. This action reflects a sketching episode taking place and switching node between two different sketching media in a sudden short moment of 'aha' event – switching from delineation of functional zoning diagram SK(1-1) over the site-plan to sketch the conceptual cross-section SK(2-1). It is weakly connected with 6 links in total (2 *backlinks* and 4 *forelinks*). It delivers very low integration value of 1.95 of a deeply structured network of relations. This idea was recalled along the process, particularly at the development sketches of the 3-D perspective, SK(4-1) and SK(5-1), where the cross-section was enhanced giving the final product of façades. Concatenated strings of information deliver median values: t-complexity 10.52 (taugs) and t-entropy 0.5 (bits/char). This node is paradoxical, because although it is an important creative insight that is retrieved many times in the design process, it delivers low integration value and low connectivity. Although the concept is structured by the cross-section idea, few actions were required to transfer the concept into design configuration. This in fact shows the architect's skills in transferring the concept into 3-D façades in a few steps relying on his own imagination.

At node 27, a switching moment starts a new design episode in order to transfer the zoning diagram SK(1-1) and conceptual cross-section SK(1-2) into a master plan SK(2-1) that proceeded from nodes 27–37. This master plan was accurately drawn to scale using a *scale-ruler*, developed and refined into more details in the following sketch SK(3-1). This sketch is quite strongly connected with 13 links (2 *backlinks* and 11 *forelinks*). It delivers the maximum integration measure in the whole linkograph of value 2.87 of a shallow network of relations. Concatenated strings of information deliver relatively high values (not the highest): t-complexity 11.23 (taugs) and t-entropy 0.55 (bits/char). This high measure reveals high diversity in the arrangements of code sets that deliver varied bits of information of structured process.

At node 37, another switching moment between two different sketching episodes took place. Sketch (3-1) is a new design episode to develop the master plan. This is a starting setup for a detailed floor plan. A tracing sheet was placed over sketch SK(2-1) to trace its main construction lines. This medium sketch SK(3-1) is highly linked with SK(2-1) since some configurations are traced with enhancement, more details and accurate measures. This designing episode lasted for long time, initiated at node 37 and continued till node 50. It is strongly connected with 3 backlinks and 16 forelinks with connectivity 19 links in total. It delivers very high integration of value 2.66 of shallow system. It is responsive to the switching moment between two sketches. Concatenated strings of information deliver the highest values in the whole linkograph: t-complexity 13.40 (taugs) and t-entropy 0.72 (bits/char). This high measure reveals high diversity in the arrangements of code sets that deliver varied bits of information of structured process.

At node 41, an action resulted from the preceding two decisions that were elaborated at nodes 38, 39 and 40.[75] Following the comments (verbalisation) on the last three preceding actions, annotations were added to label the exhibition halls 1, 2 and 3. This node is weakly connected with 1 backlink only to medium sketch SK(2-1) master plan. It delivers low integration of value 1.52 of deep system. Concatenated strings of information for this node gives the minimum t-code measures in the whole linkography: t-complexity 7.46 (taugs) and t-entropy 0.3 (bits/char). This is due to the low connectivity; the string is composed of repeating characters of 0's and thus inclines to normalise the t-code measures.

Node 51 is a switching node to start a new sketching episode SK(4-1) to design a 3D perspective for the south façade. This designing episode continued from nodes 51 until node 56. It was refined in the following sketch SK(5-1) with more details and accurate projections. This node reflects a creative leap; shifting the design from the 2-D master plan to 3-D perspective façade '*one-go sketching*'. It is a vertical transformation for the main concept that has extended the design to explore more details. This design parti was enhanced with the architect's reflection on his own imagination, articulation and sketching skills. It is connected with 6 forelinks and 4 backlinks of connectivity – 10 links in total. It delivers a median integration of value of 1.76. Concatenated strings of information deliver relatively high t-code measures: t-complexity 11.20 (taugs) and t-entropy 0.55 (bits/char), which reflects the diversity of arrangements of bits of information for the string of codes.

Node 57 is a switching node to start a new sketching episode SK(5-1), which continued until node 62. A tracing sheet was then placed over the previous sketch SK(4-1) in order to enhance the last product of the 3-D perspective façade. The concept of this sketch is not unprecedented, it is an enhancement of the preceding sketch SK(4-1). It is connected with 3 backlinks and 5 forelinks – 8 links in total. It delivers a median integration of value 1.72. Concatenated strings of information for this node give relatively high t-code measures with values t-complexity 11.17 (taugs) and t-entropy 0.55 (bits/char), which reflect diversity of arrangements in the extracted string of information comprising complex sequence of bits of information.

6.5.4 Results and Discussion

In the previous descriptions, we have explained the formation of concepts in the initiation phase and have particularly identified the critical actions and creative leaps that have affected the structure of reasoning and emergent artefacts throughout the process. With the aim of revealing the relation between the contents of design and structure of reasoning, we find the following results according to the demonstrated analyses:

> First, the formation of concept of the initial stage structured the whole design process thereafter. The interim products and stages of development 'reframed' the solution instead of creating an unprecedented novel concept. The design problem has not been restructured – no sudden paradigms shifted the design process to a different state.
>
> Second, the structure of design reasoning is incremental and consistent, indicating a recursive process of thinking.
>
> Third, the relation between the contents and the structure of reasoning is hierarchical and constructive. The concept was set up at the initiation phase; the intermediate and last stages were deliberately directed to execute the concept.

[75] See Appendix 6.3 to review the *transcription* and *coding* for this design process.

In light of the emergent patterns of linkography protocol, our aim of creating an integrative taxonomy of analyses is to reveal the context beyond the emergence of creative eureka insights and paradigm shifts to investigate the implications of the reasoning structure in the design process. This process started with an *analytic* phase of the given design programme and site-plan. Although the brief is neither structured nor specified with functional requirements or constraints, the architect initiated the concept based on traditional site analysis.

Studying the morphology of the given site-plan with the conceptual idea in the architect's mind – to express the era *before* and *after* the Spring Revolution in Egypt on 25 January 2011 – the design process was structured accordingly. The design stages were divided up and planned ahead to achieve a series of goals that serve the initial prime concept.

Translating the concept into revolutionary forms of centrifuged shapes and straggling rooflines[76] is only the architect's translation, which may have been differently articulated by different designers if pursuing a design influenced by the Spring Revolution. The transformation of ideas assures the *perseverance* of prime concept, in the form of vertical transformation (providing details and solutions to extend the concept), rather than lateral transformation, which shifts the design to explore different ideas. The interim artefacts signify the development and movement from one idea to a more detailed version of it. The architect's intention was to deepen the problem space instead of exploring different kernel ideas. This has limited the emergence of novel unprecedented ideas or sudden creative insights except those two venues that preserved the concept: the cross-section (node 14) and 3-D perspective (node 51).[77]

The balance between lateral and vertical transformations cannot be justified in this process. The prime concept was embodied from the commencement and controlled the majority of production all through the process till the end. This in fact reflects the pyramidal relation between the structure of reasoning and artefacts (contents). Figure 6.24 presents the linkograph of this design process, Figure 6.25 illustrates an annotation of the sketching episodes and critical actions in the linkograph of this design experiment, and Figure 6.26 demonstrates the stages of design process.

The concept was nourished by architectural treatments that were not novel to the conceptual form but were probably preconceived through the architect's accumulative experience, e.g. the natural lighting installations, the straggling roof, the dynamic lines in the master plan of different module structures and functional spaces.

The early notions of concept were reflected in zoning a diagram sketch SK(1-1); the idea was stimulated at the cross-section sketch SK(1-2), then conveyed into a master plan study at sketch SK(2-1). This master plan was enhanced and refined at sketch SK(3-1). The 3-D perspective façades of sketches SK(4-1) and SK(5-1) were then developed to serve the prime concept.

The emergent patterns of linkography reflect the incremental form of reasoning with consistent structured chunks of links and very few instances of long back/forelinking. This design process was not insightful but it was consistently structured with one conceptual idea that domineered the whole configuration. This is characterised by the sequence of dense actions and compact and overlapping networks of dependency relations. Having chunks of short links reflects the vertical transformation of the concept rather than lateral transformation throughout design process.

Transitional switching nodes between different sketches of designing episodes acted as *creative hinges* that transferred the concept and exchange of ideas from one medium to another. This is illuminated by the integration measurement for the 'bridging' nodes, particularly nodes 27, 37, 51 and 57. Furthermore, this process does not include *back-* or *forelinks* of long relations between early and later thoughts. It denies any probability for diverse ideas to collide or of stimulating sudden insights to occur, except for that hinge interfering in the process at node 14, extending the concept with the cross-section sketch.

[76] The architect used the description of 'straggling roof' to describe the concept of random forms. See Appendix 6.3 – node 52.

[77] This accords with Goel's definitions (1995): *vertical transformation* is 'where movement is from one idea to a more detailed version of the same idea'; *lateral transformation* is 'where movement is from one idea to a slightly different idea rather than a more detailed version of the same idea.' The lateral type of transformation does not exist in the design process of Designer 3.

Figures 6.27, 6.28, 6.29 and 6.30 show the overlay of integration, t-code measures and network analysis for the concatenated and backlink-directed relations methods on the linkograph. In those figures, it is obvious that the remarkable nodes that show significant measures are those transitional nodes switching from one sketching medium to another. Table 6.5 shows all the measurements for this design case study.

Creativity is highly structured in this design process. This is signified by the *perseverance of concept* and the *interdependency* between the interim artefacts. This is distinguished through the following actions:

- Conjecturing the design configuration is basically determined with *analysis* and *synthesis* phases of design.
- Decision making to orient the functional requirements with the design spatial configuration is predominantly dependent on the *morphology of form* and *site analysis* of orientation towards the north, greenery area and river.
- Signs of idiosyncrasies are immense in this experiment. Composition of forms, architectural treatments and decisions about the spatial organisation were not based on rational justification, but rather reflected the architect's reflected imagery of theoretical conceptual idea and the reliance on high-calibre sketching and imagination skills.

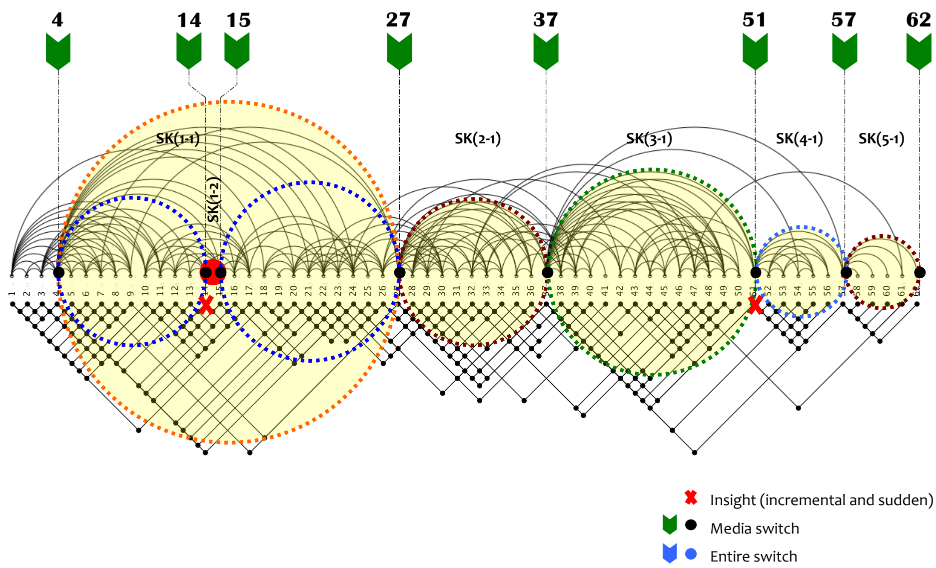


Figure 6.24 Linkography Protocol of the design process (Case Study 1, Designer 3)

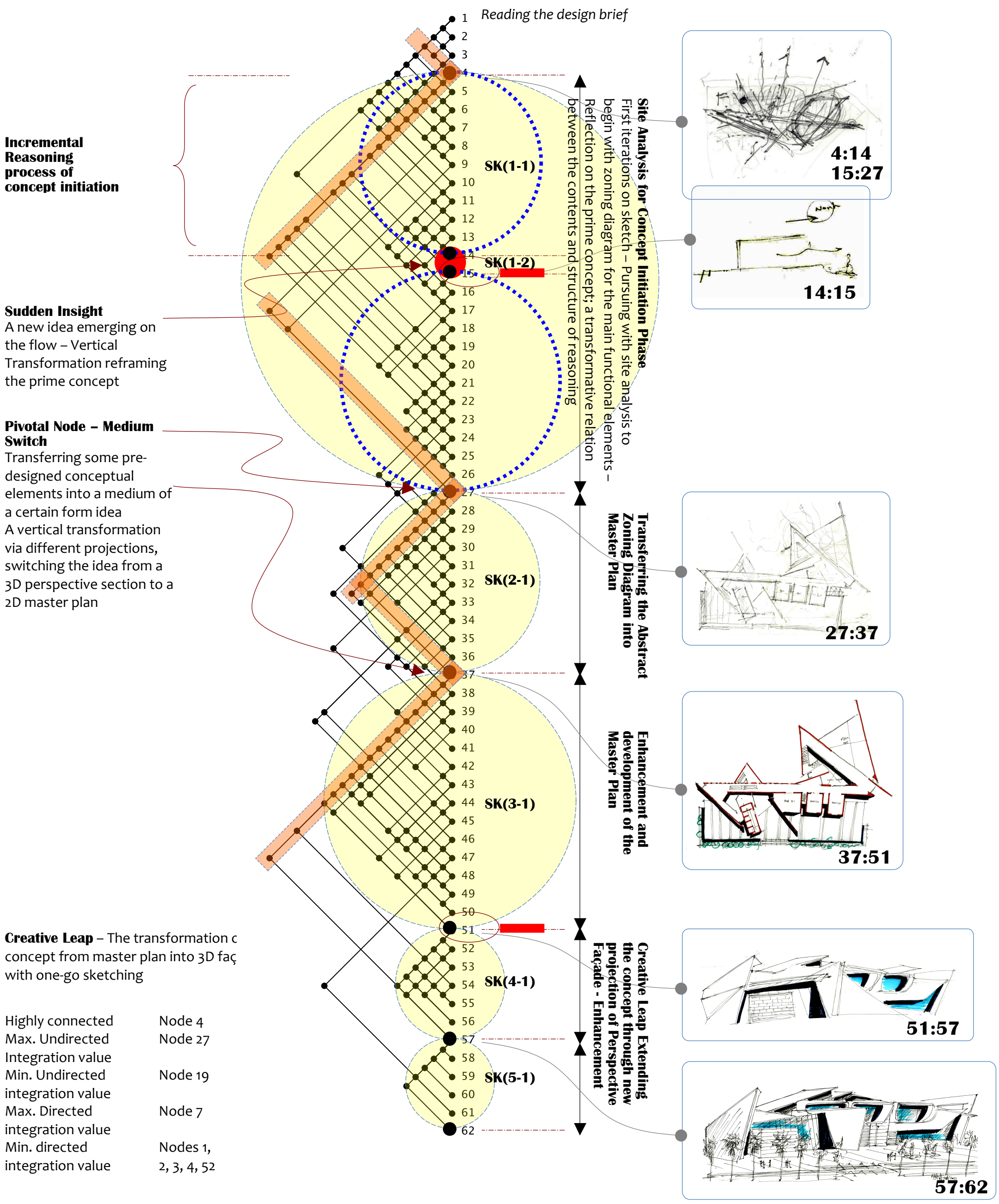


Figure 6.25 Annotation of creative actions and insights, sketching contents, concept transformations via back/forelinking and sketching exchanges

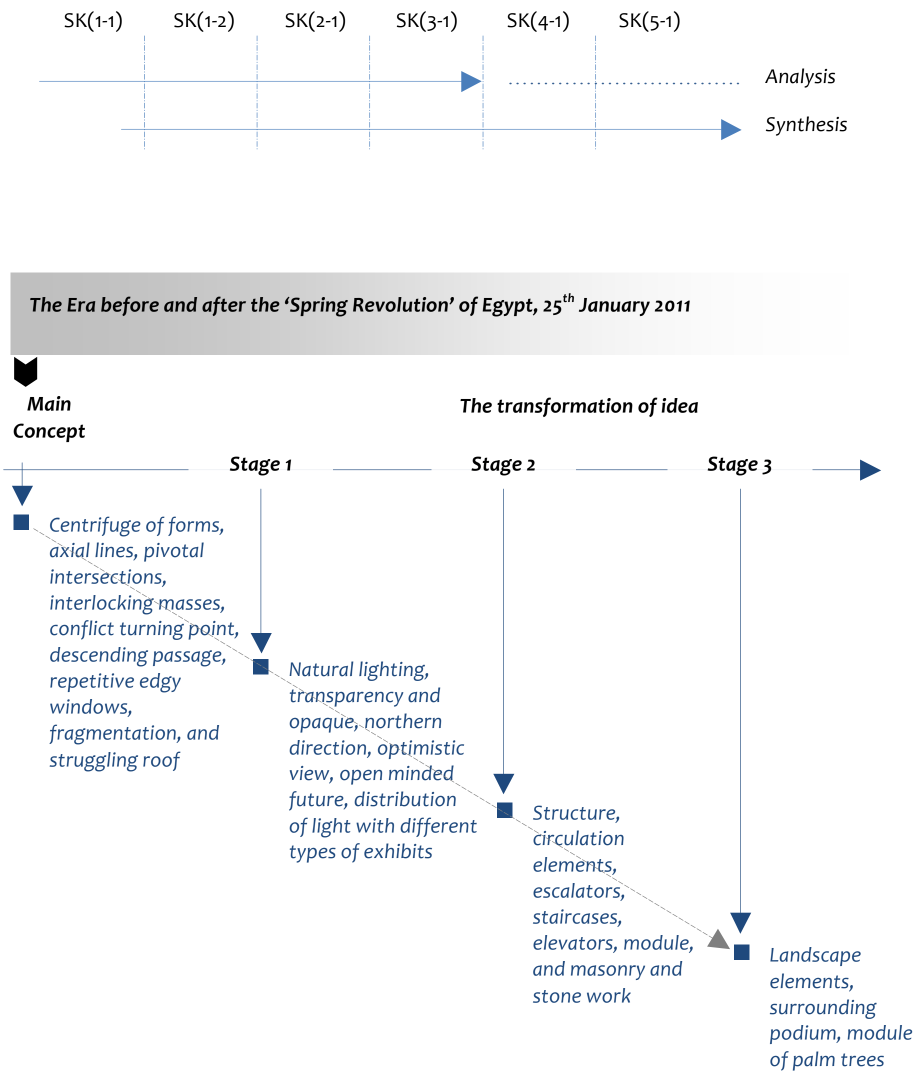


Figure 6.26 Analysis and synthesis through the stages and sketching media (Case Study 1, Designer 3)

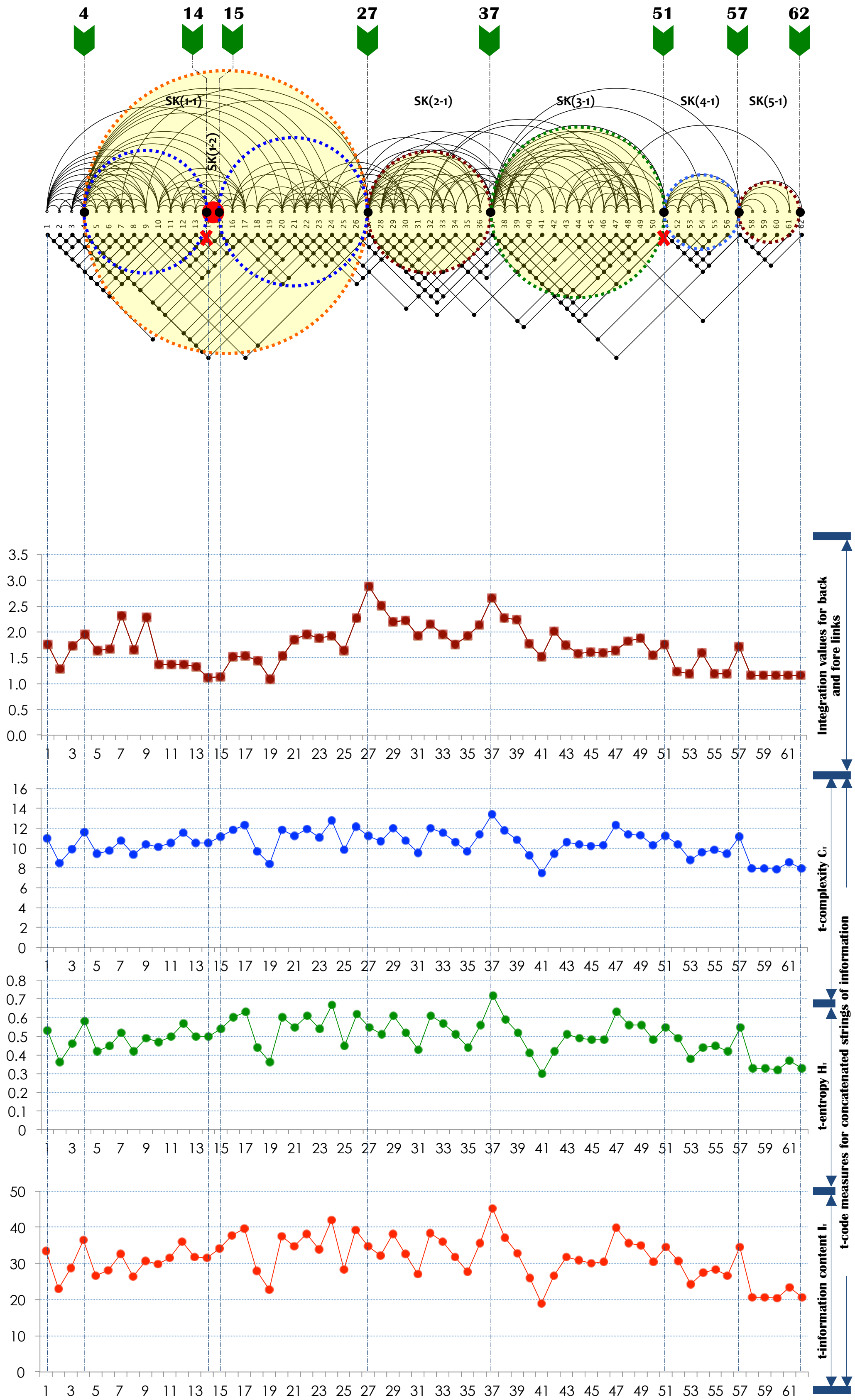


Figure 6.27 Quantitative Measures for '*Concatenated*' relations (Case Study 1, Designer 3)

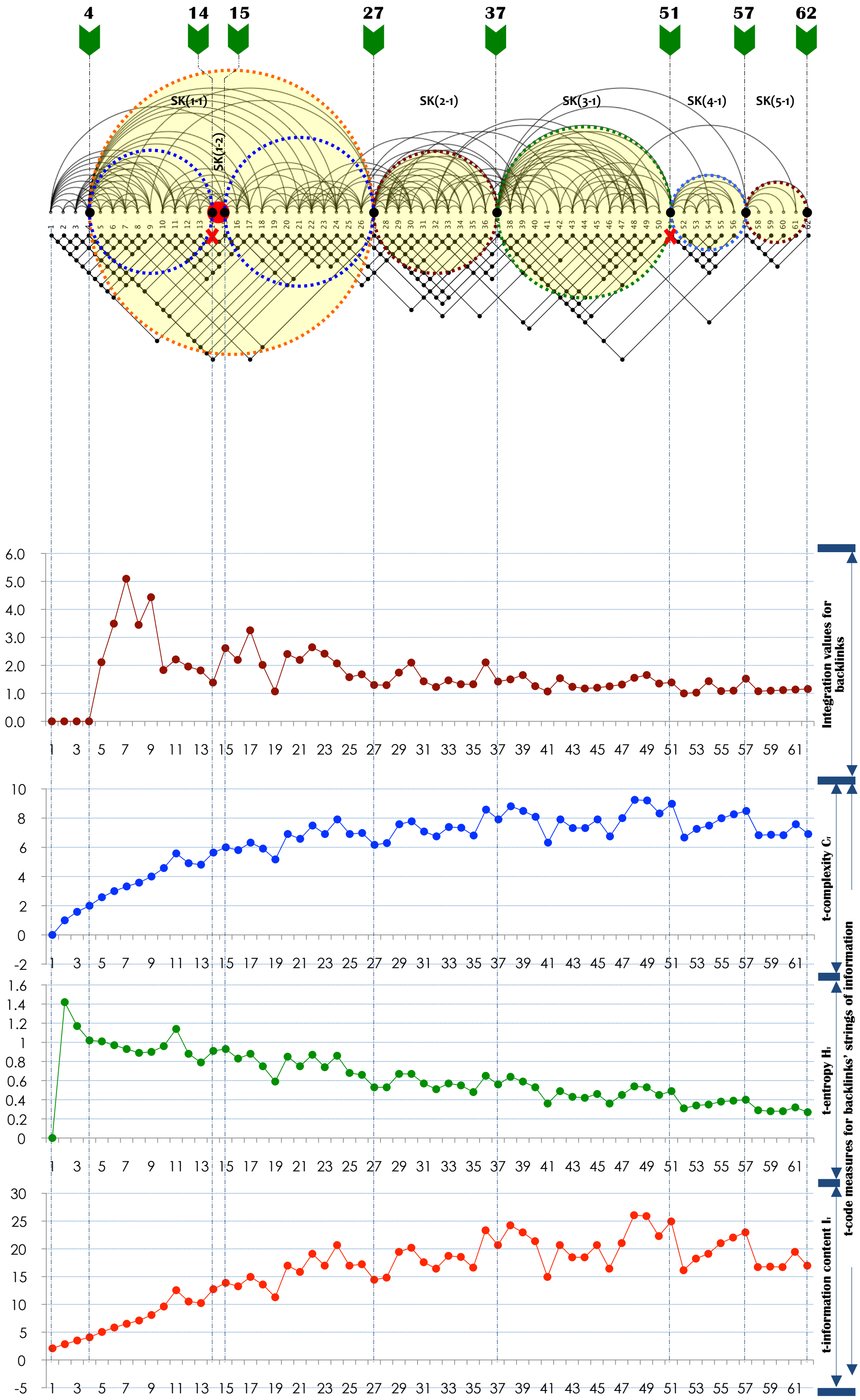


Figure 6.28 Quantitative measures for *backlink-directed* relations (Case Study 1, Designer 3)

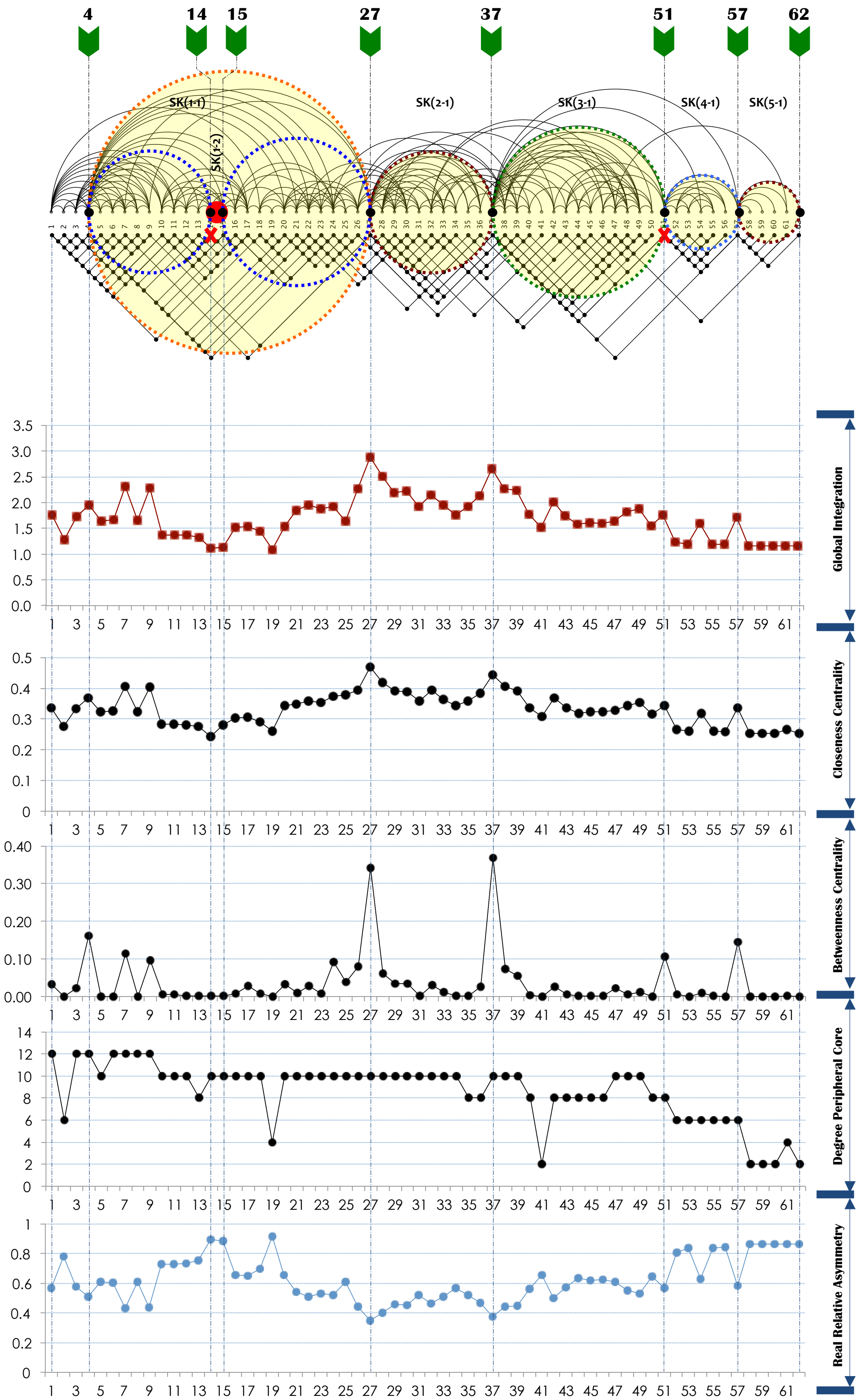


Figure 6.29 Network analysis for *concatenated* relations (Case Study 1, Designer 3)

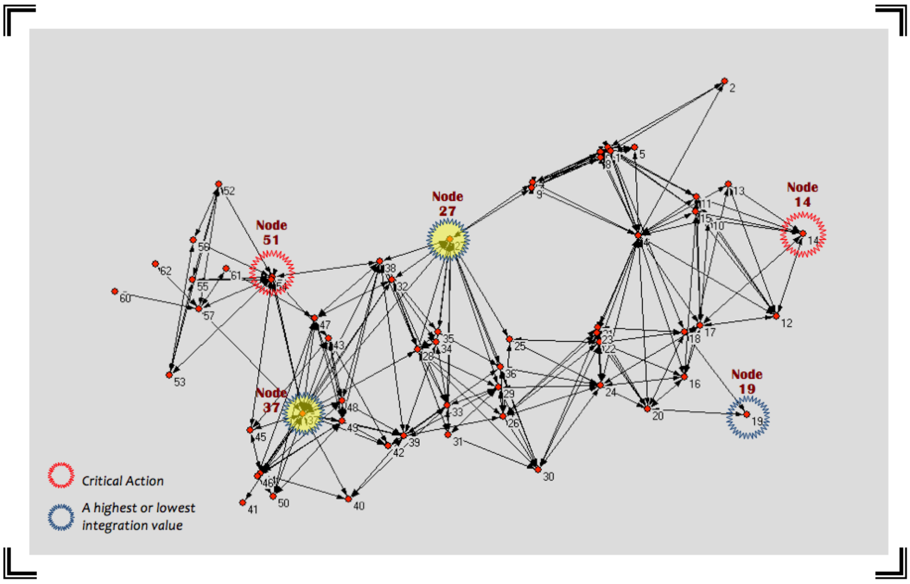


Figure 6.30 Quantitative measures for *backlink-directed* relations (Case Study 1, Designer 3)

Table 6.5 All the quantitative measurements for the linkograph protocol (Case Study 1, Designer 3)

#	Undirected Measurements								Directed Measurements					
	Closeness Centrality	Betweenness Centrality	Integration	Real Relative Asymmetry RRA	Degree Peripheral Core	T-complexity Concatenated strings	T-entropy Concatenated strings	T-info Concatenated strings	Integration	Closeness Centrality Backlink Relations	Betweenness Centrality Backlinks Relations	T-complex Back strings	T-entropy Back strings	T-information Back strings
1	0.34	0.03	1.76	0.57	24.00	10.95	0.53	33.49	0.00	0.00	0.00	0.00	0.00	2.09
2	0.27	0.00	1.28	0.78	10.00	8.47	0.36	22.88	0.00	1.00	0.00	1.00	1.42	2.84
3	0.33	0.02	1.73	0.58	24.00	9.87	0.46	28.70	0.00	1.00	0.00	1.58	1.17	3.50
4	0.37	0.16	1.95	0.51	24.00	11.61	0.58	36.51	0.00	1.00	0.00	2.00	1.02	4.08
5	0.32	0.00	1.64	0.61	20.00	9.39	0.42	26.67	2.11	0.80	0.00	2.58	1.01	5.04
6	0.33	0.00	1.66	0.60	24.00	9.75	0.45	28.21	3.49	0.83	0.00	3.00	0.97	5.84
7	0.41	0.11	2.31	0.43	24.00	10.75	0.52	32.60	5.09	0.86	0.00	3.32	0.93	6.51
8	0.32	0.00	1.65	0.61	24.00	9.34	0.42	26.45	3.45	0.78	0.00	3.58	0.89	7.10
9	0.40	0.10	2.29	0.44	24.00	10.34	0.49	30.75	4.44	0.80	0.00	4.00	0.90	8.09
10	0.28	0.01	1.37	0.73	20.00	10.11	0.47	29.74	1.83	0.60	0.00	4.58	0.96	9.62
11	0.28	0.01	1.37	0.73	20.00	10.52	0.50	31.57	2.21	0.63	0.00	5.58	1.14	12.56
12	0.28	0.00	1.36	0.73	20.00	11.52	0.57	36.12	1.96	0.58	0.00	4.91	0.88	10.52
13	0.28	0.00	1.33	0.75	16.00	10.55	0.50	31.70	1.82	0.55	0.00	4.81	0.79	10.24
14	0.24	0.00	1.12	0.89	20.00	10.52	0.50	31.57	1.39	0.46	0.01	5.64	0.91	12.74
15	0.28	0.00	1.13	0.88	20.00	11.11	0.54	34.20	2.62	0.61	0.01	6.00	0.93	13.88
16	0.30	0.01	1.52	0.66	20.00	11.87	0.60	37.74	2.20	0.56	0.00	5.81	0.83	13.26
17	0.31	0.03	1.54	0.65	20.00	12.29	0.63	39.71	3.25	0.64	0.02	6.32	0.88	14.95
18	0.29	0.01	1.44	0.70	20.00	9.68	0.44	27.88	2.02	0.52	0.00	5.91	0.75	13.58
19	0.26	0.00	1.09	0.92	8.00	8.43	0.36	22.71	1.07	0.35	0.00	5.17	0.59	11.29
20	0.34	0.03	1.53	0.65	20.00	11.83	0.60	37.56	2.41	0.54	0.05	6.91	0.85	16.98
21	0.35	0.01	1.85	0.54	20.00	11.21	0.55	34.67	2.20	0.53	0.00	6.58	0.75	15.85
22	0.36	0.03	1.95	0.51	20.00	11.95	0.61	38.12	2.65	0.55	0.01	7.49	0.87	19.11
23	0.35	0.01	1.88	0.53	20.00	11.04	0.54	33.91	2.42	0.54	0.00	6.91	0.74	16.98
24	0.37	0.09	1.92	0.52	20.00	12.75	0.67	41.97	2.07	0.59	0.01	7.91	0.86	20.68
25	0.38	0.04	1.64	0.61	20.00	9.79	0.45	28.38	1.58	0.41	0.00	6.91	0.68	16.98
26	0.39	0.08	2.26	0.44	20.00	12.17	0.62	39.16	1.68	0.42	0.00	6.98	0.66	17.23
27	0.47	0.34	2.87	0.35	20.00	11.23	0.55	34.76	1.30	0.41	0.01	6.17	0.53	14.44
28	0.42	0.06	2.50	0.40	20.00	10.64	0.51	32.10	1.29	0.35	0.00	6.29	0.53	14.83
29	0.39	0.03	2.19	0.46	20.00	11.98	0.61	38.24	1.74	0.42	0.01	7.58	0.67	19.46
30	0.39	0.04	2.22	0.45	20.00	10.75	0.52	32.60	2.10	0.45	0.02	7.78	0.67	20.20
31	0.36	0.00	1.92	0.52	20.00	9.49	0.43	27.09	1.43	0.36	0.00	7.08	0.57	17.59
32	0.39	0.03	2.15	0.47	20.00	12.00	0.61	38.35	1.23	0.33	0.00	6.75	0.51	16.44
33	0.36	0.01	1.95	0.51	20.00	11.52	0.57	36.12	1.46	0.36	0.00	7.39	0.57	18.74
34	0.34	0.00	1.76	0.57	20.00	10.58	0.51	31.84	1.33	0.34	0.00	7.34	0.55	18.55
35	0.36	0.00	1.92	0.52	16.00	9.64	0.44	27.73	1.33	0.34	0.00	6.81	0.48	16.63

36	0.38	0.03	2.13	0.47	16.00	11.39	0.56	35.51	2.11	0.44	0.02	8.58	0.65	23.34
37	0.45	0.37	2.66	0.38	20.00	13.40	0.72	45.14	1.42	0.35	0.00	7.91	0.56	20.68
38	0.41	0.07	2.26	0.44	20.00	11.75	0.59	37.20	1.50	0.36	0.00	8.81	0.64	24.24
39	0.39	0.05	2.24	0.45	20.00	10.81	0.52	32.84	1.65	0.37	0.01	8.49	0.59	22.97
40	0.34	0.00	1.77	0.56	16.00	9.25	0.41	26.06	1.26	0.30	0.00	8.09	0.53	21.38
41	0.31	0.00	1.52	0.66	4.00	7.46	0.30	18.99	1.07	0.27	0.00	6.32	0.36	14.95
42	0.37	0.03	2.01	0.50	16.00	9.39	0.42	26.67	1.54	0.35	0.00	7.91	0.49	20.68
43	0.34	0.01	1.74	0.57	16.00	10.58	0.51	31.84	1.24	0.29	0.00	7.32	0.43	18.48
44	0.32	0.00	1.58	0.63	16.00	10.39	0.49	30.98	1.17	0.29	0.00	7.32	0.42	18.48
45	0.32	0.00	1.61	0.62	16.00	10.17	0.48	30.01	1.20	0.29	0.00	7.91	0.46	20.68
46	0.32	0.00	1.60	0.63	16.00	10.29	0.48	30.51	1.25	0.30	0.00	6.75	0.36	16.44
47	0.33	0.02	1.64	0.61	20.00	12.32	0.63	39.88	1.32	0.30	0.00	8.00	0.45	21.04
48	0.34	0.01	1.82	0.55	20.00	11.39	0.56	35.51	1.56	0.33	0.01	9.25	0.54	26.06
49	0.35	0.01	1.88	0.53	20.00	11.29	0.56	35.02	1.66	0.34	0.01	9.21	0.53	25.90
50	0.32	0.00	1.55	0.64	16.00	10.29	0.48	30.51	1.35	0.30	0.00	8.32	0.45	22.30
51	0.34	0.11	1.76	0.57	16.00	11.20	0.55	34.62	1.39	0.31	0.00	8.98	0.49	24.94
52	0.27	0.01	1.24	0.81	12.00	10.34	0.49	30.75	1.00	0.24	0.00	6.67	0.31	16.15
53	0.26	0.00	1.20	0.84	12.00	8.81	0.38	24.24	1.03	0.24	0.00	7.26	0.34	18.24
54	0.32	0.01	1.59	0.63	12.00	9.58	0.44	27.48	1.43	0.31	0.00	7.49	0.35	19.11
55	0.26	0.00	1.20	0.84	12.00	9.81	0.45	28.43	1.08	0.25	0.00	7.99	0.38	21.02
56	0.26	0.00	1.19	0.84	12.00	9.39	0.42	26.67	1.10	0.25	0.00	8.26	0.39	22.04
57	0.34	0.15	1.72	0.58	12.00	11.17	0.55	34.49	1.52	0.32	0.01	8.49	0.40	22.97
58	0.25	0.00	1.16	0.86	4.00	7.91	0.33	20.68	1.08	0.24	0.00	6.83	0.29	16.72
59	0.25	0.00	1.16	0.86	4.00	7.91	0.33	20.68	1.10	0.25	0.00	6.86	0.28	16.80
60	0.25	0.00	1.16	0.86	4.00	7.83	0.32	20.40	1.12	0.25	0.00	6.83	0.28	16.72
61	0.27	0.00	1.16	0.86	8.00	8.58	0.37	23.34	1.14	0.26	0.00	7.58	0.32	19.46
62	0.25	0.00	1.16	0.86	4.00	7.91	0.33	20.68	1.16	0.25	0.00	6.91	0.27	16.98

Switching medium node
Creative insight
Highest vs. lowest degree of integration or t-code measures

6.6 In Conclusion

This study adopted the approach of joint analysis to describe the role of creativity in design reasoning processes. In the experiments presented, the compatibility of results between quantitative and qualitative analysis is verified through the variety of design situations in the three case studies. Accordingly, *multilevel complexity* characteristics of design reasoning due to reflective practice with emergent artefacts is revealed, showing how the emergent products responded to the design problem and set of goals. The formation of concepts evolving through the design processes indicated a variety of factors that form the reasoning process, either 'rational' incremental reasoning or 'non-rational' reasoning.

We conclude that the *procedural* components of design stem from rational reasoning. It adopts convergent thinking and is likely to execute the design concept in a consistent (systematic) manner, which is detected in the linkograph by: high 'connectivity' of links among sequential actions (short links), 'interdependency' between design actions and interim artefacts, and incremental concept development. On the other hand, the *contextual* components and *affordances of environment* stem from non-rational reasoning. This approach adopts divergent thinking when the designer reflects back on earlier thoughts where sudden mental insights are likely to occur while the concept's synthesis merges different thoughts (i.e. combining different seeds and conceptual elements in one solution), which is detected in the linkograph by: structured networks with long back/forth linking, back reflections (e.g. sketching to generate new forms back to the mind), and the unexpected discovery of sudden mental insights.

From the qualitative outcomes (descriptions and ethnographic observations) and linkography analyses, we infer the relevance of 'bridging' and 'disconnecting' moves to cause 'paradigm shifts', 'sudden mental insights', and 'creative actions'. This relevance is consequently vital to detect the relation between the 'contents' and 'structure of reasoning' in the design process. To this extent, paradigm shifts are forms of non-rational reasoning that are caused by: breaking out of a frame of reference, shifting to a new one, divergent thinking, and occurrence of subconscious mental insights. Forming non-rational syntheses serves to introduce new boundaries to the design requirements, which encourages the exploration of new dimensions that have not been explored before to extend the design concept. The 'displacement of concepts' and 'transformation of ideas' are approaches that can provide either 'rational' or 'non-rational' modes of reasoning. However, 'multiple exchanges of information' and 'long back- and forelinking' are capacities that increase the probability of sudden mental insights of unprecedented solutions occurring.

Configurations of a linkograph are responsive to a variety of forms of reasoning. Different types of networks can be characterised in the cases presented that distinguish the form(s) of reasoning for the state of design beyond. However, two major types are distinguished in order to advance our discussion: (1) *Consistent* patterns are structured by the compactness of links that reflect the *interdependency of transformation* from one design medium to another, which in consequence reflect the rational reasoning of iterative thinking and the perseverance of primary concept from one stage to another; (2) Insightful networks are structured by long links between *earlier* and *later* design actions that signify the comparisons and multiple exchanges of information between sketches and different designing media. This is associated with the non-rational form of reasoning and divergent thinking.

While convergence 'reframes' the initial concept (original solution) and reflects a 'transformative' process of design, 'divergence' could stimulate either 'transformative' process (if an insight of creative action occurs in an incremental form of reasoning that reframes the initial solution) or 'hierarchical' process (if a sudden mental insight of paradigm shift drastically restructures the design problem and directs the following actions to a particular goal to generate the new concept 'solution'). In convergence, creative insights are dependent on the context of design, in relation to the preceding actions. In divergence, they are independent and disconnected from the preceding actions or from the prevailing flow.

An *insightful* process is distinguished by its long back/forelinks between earlier and present thoughts. It constitutes divergent thinking, a capacity for creativity (Robinson, 2010). Sudden insights act to diversify the process as sources for the formation of novel concept. They might emerge from the *synthesis* with an old idea, conceptual form or conceptual element – coined in Johnson (2010) as 'a collision with an old slow hunch'

The multiple exchanges of ideas between different sketches (interim artefacts) stimulate the emergence of creative ideas and unpredicted solutions that appear during the transition between different chunks of links in terms of bridging nodes between sub-networks in the linkograph. Bridging and splitting nodes are needed to investigate the structure of networks in linkographs.

Design tools and media for the externalisation of imagery into conceptual drawings of design configuration characterise the type of design process and signify the emergent forms of reasoning that are taking place. Goldschmidt (1994) identified two types of sketching: one aims to transform imagery into new forms of combinations that reflects a 'rational' mode of reasoning; the other generates new imagery of forms in the mind and reflects a 'non-rational' form of design thinking. From the descriptions we have presented for the case studies in this chapter, the detection of creative insights and interpretation of sketches of interim artefacts, we conclude that:

- The first type of sketching shows hierarchical relation between the contents and structure of reasoning. It is a *structured* model of design process to achieve 'predefined' goals through a sequence of design actions.
- The second type shows the *transformational* process between the artefacts (contents) and the mind (structure of reasoning). It is a 'reflection-in-action' model that brings unprecedented ideas to the context of reasoning that the architect has not thought of rationally and might redefine the initial set of goals.

The correlation between various quantitative measurements with qualitative descriptions of sketches is very useful to unveil the influence of design actions on the reasoning processes and on the formation of products across the interim stages until the final product. Depth measure indicates the integration of networks for each action within the whole configuration of the linkograph. This can be revealed at either 'local' or 'global' levels. There are two types of network integration: (1) shallow networks are highly integrated delivering low mean depth values; and (2) deep networks are modestly integrated delivering high mean depth values. This provides us with an insight to extend our investigation on the nature of networks and the effect of sudden mental insights and paradigm shifts on two different situations of design.

Directed linkography is a method proposed to quantify the network of each action in the design process in two situations: (1) synchronous emergence (quantifying the backlinks only), and (2) diachronic after completion of the whole process (quantifying the concatenated networks of backlinks and forelinks).

This method is introduced in Chapter 8 with the aim of revealing the role sudden insights play on the transformative versus hierarchical models of design.

Computation of the character strings of information unveils the diversity of arrangements of codes that provides a profound insight into investigating the probability of association between complexity and entropy measures for each action and the interpretation of creativity and innovation in design processes.

This study contrasted the emergence of creative insights against patterns of design reasoning in unstructured design case studies. According to the results of the experiments presented in this chapter, we argue that modes of reasoning vary between *incremental reframing* of the prevailing concept and *non-incremental restructuring* of the problem. Creative stimulations occur in both contexts. In the following chapter, we examine these conclusions in a different type of design case study that is highly structured and specified with various conditions and constrains.

6.7 Key Findings of Chapter 6

- The design process varies from *procedural* to *contextual* depending on how the design products are associated with the set of predefined goals: whether the actions are directed to achieve the goals or, in reverse, reform the set of initial goals.
- The design process takes a different state with the sudden occurrence of mental flashes, which requires investigation.
- This study describes the experimental linkography research. It is important to note that the identification of nodes and description of links in each design experiment is made by describing the quantitative and qualitative analyses for each emergent action in the design process.
- The designers undertaking the work are not contributing in the transcription, segmentation and coding processes but their retrospective comments and external verbalisations were considered in this coding process.
- The validity and reliability of this descriptive model in identifying the critical actions in the creative design process by integrating qualitative and quantitative analysis is confirmed.

Chapter

7 Creative Discovery and Design Reasoning in Structured Architectural Case Studies
Validation of the proposed descriptive scheme

This chapter investigates the context beyond the formation of concepts of creative ideas in highly structured and specified design problems. It examines the imposition of specific functional requirements associated with unpredicted constraints on the architect's thinking process on the probability of sudden insights occurring and shifting the prevalent design paradigm into a different state. The validation for the proposition of a descriptive model is further verified through three different design case studies. The interplay between design media, back- and forelinking between interim products and multiple exchanges of information between sketches play vital roles in problem analysis and solutions synthesis to overcome fixation and disruptive effects and to shift the design paradigm from one frame of reference to another. This empirical study aims to show the influence of a highly structured design brief; whether it constrains or provides freedom to the architect to design creatively.

In Chapter 6 we presented an empirical study on unstructured architectural case studies for a familiar *recreational* project that provided free rein to the architects to design their own ideas for an expo pavilion. Our intention was to examine whether reflections with preconceived images (if they exist) allow the architect to create syntheses of several solutions for the theme: *what would the country's imagined pavilion look like?* We assumed that *synthesis* is a capacity for unpredicted solutions and sudden creative insights to occur in the design process that might drastically restructure the design entire state. *Convergence* versus *divergence* was looked at in this discourse.

In this chapter, we examine different types of architecture design problems for an unfamiliar project in the area of industrial design. The task is to design from a highly structured and specified brief for a *cheese factory*. We assume that most architects would not be familiar with such an entity and that under normal conditions extensive prior research would be required. We provide them with a detailed programme that includes some functional elements that are quite technical; e.g. refrigerator storage for raw material and products; processing line including steriliser and multifunctional tubular pasteuriser; packing line; and heating, ventilation and air conditioning (HVAC) control room. Figure 7.1 shows the design brief in detail.

Our participating architects are further constrained in the experiment by the imposition of an external condition midway through the process. An additional functional element to the design programme is requested to be included in the final parti within the same time limit.

Participating architects are the same invitees as in the unstructured design experiments presented in Chapter 6. As stated earlier, the design briefing is introduced to the architects just before the design process commences. They have not received any introduction beforehand to avoid any direction towards preconceived projects. This is to avoid any advance research or intrusion of particular mental imagery that might affect the objectivity of the context of experimentation and data collection.[78]

This chapter aims to investigate any possible triggers that contribute to the sudden occurrence of drastic changes imposing on the prevalent design flow. Prior to this final stage experiment, a set of constraints was tested in pilot studies.[79] *What 'type' of external constraint are we imposing: a mere 'addition' to the functional programme or a 'change' to the programme*? We argue that adding a functional element to the programme midway through the process has a different impact than changing the whole or some part of the programme. In the real world, every designer is likely to meet unforeseen problems that may change the whole concept. Such constraints were applied to the pilot experiment. Observing architects' attempts to deal with radical external constraints, our ethnographically collected observations are twofold:

[78] Instructions prior to the experiment and Health and Safety consent forms are shown in Appendix 3.1. All the experiments took place at the Bartlett School of Graduate Studies, University College London.
[79] See Chapter 3 to review the pilot experiments.

First, the prevalent concept might struggle to reach an end product due to the difficulty in solving an unexpected problem in the limited time. This might affect the design process to the extent of causing fixation or complete blockage. In one experiment, the subject was provided with a free programme to design a conceptual idea for the *expo pavilion* in the first half of experiment. Midway through the process, we presented a radical problem, e.g. 'The outlined site has a stand of old trees that the authority wants to retain' or 'There is a utility line passing across the site (indicated on the enclosed map) whose protection prohibits any construction work'. While one architect could not modify the prevalent concept in line with the newly imposed request, the second ignored the request completely, commenting: '*The solution might include those trees with no change introduced to the mass*'; or '*There must be a way to construct the pavilion and protect the utilities' pipe lines in the same construction process*'. Hence, the quality of the final outcome is undermined by such shallow decisions.

Second, the concept comes to a sudden halt while the architect tries to work out the deviations needed to solve the imposed problem. Realisation of the effect of the new problem might extend the concept's sudden halt into a 'dead end'. If the architect decides to change the entire concept completely the time limits might prevent a final satisfactory outcome being reached.

7.1 Context of Experiments

In this design experiment we are going to examine how the imposition of a constraint that requires the architect to add a new functional element to the initial design programme affects ability to cope with the time factor and to avoid any other reasons that might put the whole process to sudden halt. In Chapter 6, the outcomes of *unstructured* design cases show that the emergence of sudden mental insights and formation of novel concepts are caused either by *incremental reasoning*, based on *synthesis* and *transformation* (creating unpredicted between various ideas), or by *non-incremental reasoning*, based on *divergence* (capacity for creative thinking), and *paradigm shift* (breaking out a *frame-of-reference* and shifting to a new one).

In this chapter, however, if the *structured* design brief and *imposition of constraint* lead to different outcomes from those of *unstructured* design, there are other variables beyond innovation of creative design that cannot be examined directly through the type of *absence or appearance* controlled experiments. Contrasting the outcomes of *unstructured* versus *structured* design cases provides insight into whether rules exist that govern or motivate *structured creativity*. In this case, we measure the importance of any design *utterance* occurring in the design process from the *value* and *creative quality* it contributes to the overall design concept.[80]

Our definition of novelty is *to come up with an unprecedented solution that has not been thought of before in the design process*, which changes the design problem into a well-defined solvable state. With regards to the main research question, investigating the relation between the *content of design* and *structure of reasoning* is determined by how the action contributes to the following actions and how it directs the interim artefacts. A variety of scenarios is proposed to interpret the formation of novel concepts in the design process:

First, if a series of dependent actions contributes to the generation of a novel solution, the context of design is verified as *incremental reasoning*. However, if the emergence of novel solution is incidental, its process is counted as *non-incremental* reasoning.

Second, determining the effect of sudden mental insights on the relation between the 'contents of design' and 'structure of reasoning' is pertinent to how they deal with the initial set of goals. If the emergent insight reframes the prevalent solution and preserves the initial goals, it reflects an incremental context of reasoning. And if it restructures the problem and redefines the initial goals, it reflects an insightful reasoning process. Hence, we enquire: *what is the type of insight emerging relevant to a 'transformational' process or a 'hierarchical' process*?

Answering this question relates to the design actions following the emergence of insight (creative idea). If the sudden occurrence of insight directs the following actions and interim artefacts to

[80] See Chapter 4 and Appendix 4.1 to review the taxonomy of creative qualities and identification of design eureka moments.

achieve a certain goal, the relation between the 'contents' and 'reasoning' is *hierarchical*. If the sudden insight affects and receives reflections from the following actions, the relation is *transformational* and continues developing until another drastic change occurs, and so forth. *Redefinition* of goals throughout the design process is caused by either *transformational* or *hierarchical* process. This hypothesis is examined in this chapter.

7.2 Case Study 2: Structured, Specified, and Constrained Design Brief

The architects were requested to design a factory that makes cheese products. The design brief was provided with detailed functional requirements that include:

The production hall: consists of two processing lines: one for 'milk steriliser' and 'multifunctional tubular pasteuriser', another for 'packing and preparing products for marketing'. The building area is to fit within 50% of the total plot area. The boundary is highlighted in the attached site plan with the design brief and determined within a maximum height of 12 metres.

The programme determines the utilities: 'administration offices', 'refrigerator storage', 'HVAC control room', 'rest room for workers, and WCs'. Instructions are provided covering the following points: a request to design an innovative structural concept for the 'production hall', 'indirect lighting and thermal control', and 'sterility'.

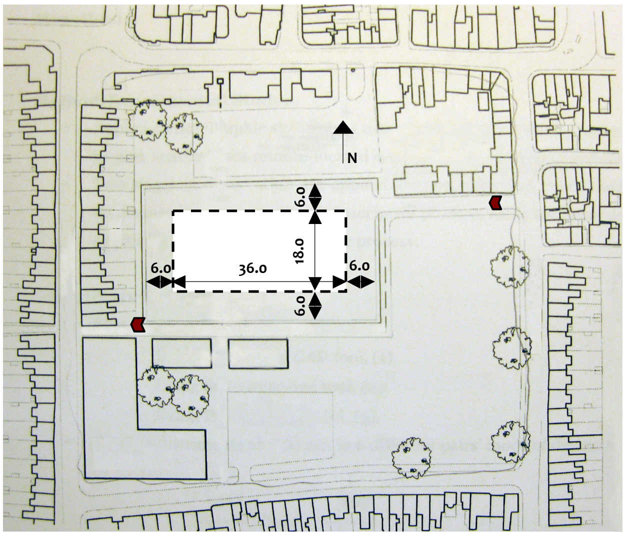
Imposed constraint: to increase the constraining conditions on the architect's cognition and see the resulting performance throughout the rest of the design process, a new request is added to the functional programme midway through the process to add an 'exhibition area' for displaying and selling products.

Time allowed for this case study was one hour, as in the unstructured cases of the pavilion design task. The aim was to generate as many solutions as possible within the determined time. However, the design brief specified certain drawings to be included: master plan, cross-section, front façade and 3-D perspective. The process was video-recorded and the architects were asked to comment retrospectively on the formation of concept through the interim products in serial order. Figures 7.1 and 7.2 show the design brief of the functional programme.

In the following sections, the design processes for the three architects invited to participate in the *cheese factory* experiment are described. These are the same individuals who participated in the Expo Pavilion experiments. Linkography protocol is constructed for each case, associated with qualitative descriptions and quantitative measurements that are processed to analyse the graphs. Our aim for these descriptions is to reveal the context in which creative ideas emerge and the implications of sudden creative insights on the structure of reasoning in the design process.

Cheese Factory:

Design Briefing



Scenario:

You are requested to design a cheese factory proposed by the outlined rectangular area on the provided site. The design should be built on 50% of this footprint. The remained area is for vehicle manoeuvring and parking. Two loading docks on two different sides must serve this factory; one is used for feeding-in row material and another to load products out to the market. Each dock should include two vehicles clearance area.

The required functions are:

1. Refrigerator storages for row material and another for products.
2. Main industry hall on 50% of built area, consists of:
   a) Processing line: steriliser and multifunctional tubular pasteurizer for milk, yoghurt and cheese.
   b) Packing line.
3. Administration offices.
4. HVAC control room.
5. Rest room and WCs.
6. Parking area for six cars.

Instructions for the main production hall:

1. The main hall should remain sterile (purified) without permitting open air.
2. An innovative construction concept for an open-plan space with fewer posts as possible.
3. Accessibility to controlled indirect lighting.
4. Maximum height to exceed is 12 meters.

Time allowed is 1.0 hour. The purpose of this study is to generate as many solutions as possible. You are required to verbalise your thoughts throughout the entirety of the study. Drawings required:

- Plan.
- Section
- 3D-model/perspective.

Good Luck

Figure 7.1 Design brief for structured architectural Case Study 2

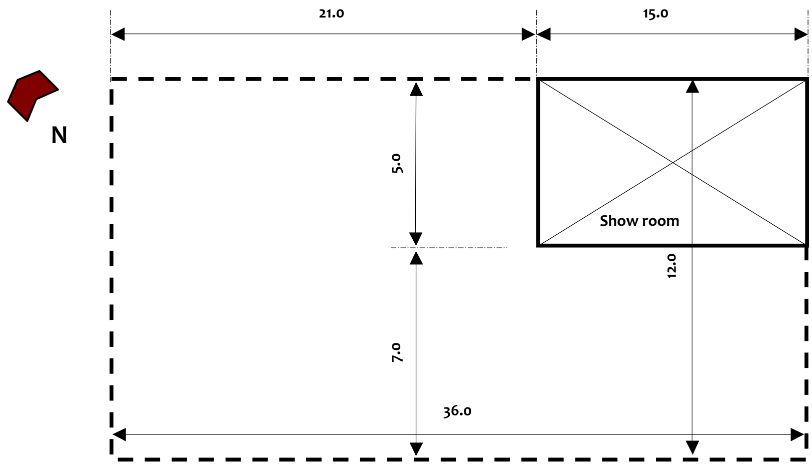
New Request:

Dear Architect,
On behalf of the client, you are requested to include a showroom attached to the factory. This is to provide customers with information on the products and to setup marketing plans with clients.
This show room must include lounges and offices to discuss selling plans with dealers in addition to a meeting room for the staff. It could be a space whether vertically or horizontally separated from the factory. The gross area remains the same however and the added showroom must be included within 40% of the building's foot print area without reducing the main functional programme percentages (highlighted in the original design brief).

You are given an indicated proposal (below) to place the showroom within the given dimensions and orientation, however you are free to make another suggestion and reasonably amend the design. It might help to split the extension and visitors circulation somewhere else apart the master plan. Specify your reasons in any case.

Probably you might divide the building's height to few levels more.
Please make any changes you find to the circulation routes, functional areas around, entrances, lobbies and parking … etc.

Present your drawings to give a better understanding on your proposed concept in the time remains.



Cross-Section – Scale to fit

Thank You

Figure 7.2 Imposition of external constraint of an addition functional requirement added to the design brief

7.3 Designer 1 – Case Study 2 Structured Brief for *Cheese Factory*

7.3.1 Description of Concept Initiation

Through *self-discussion* and *elaboration* processes relating to the functional programme and requirements, the architect reflected the first notions on the design brief and outlined the key elements for the concept initiation phase. During the process, syntheses were created between those conceptual elements to develop the design on. Scribbles at this early stage while reading the given scenario included: *zoning diagram for master plan*, *conceptual section* crossing through the production hall, detail of *indirect lighting*, *loading dock* for two vehicles, and annotations that were added to highlight some keywords in the body text. This was provided with *site analysis*, *sun path* diagram and *orientation* to the prevailing winds. The main entrances and circulation for vehicle routes in and out of the site were indicated on the enclosed site layout.

The *vertical separation* between the production hall and offices area including all pertinent decisions for the *spatial zoning* were decided in this initiation phase (offices for the administrative zone were located at an upper mezzanine level overlooking the production hall on the ground floor). The distribution of functional utilities in relation to the main hall were also outlined and drawn at this early stage.

In the intermediate stage, these decisions were articulated in detailed drawings and extended into different master plan studies to investigate all possible spatial configurations, arrangements and distribution of functions that have direct relation to the main production hall, e.g. storage area, refrigerator and loading docks. The conceptual idea for a cross-section sketch was extended to design the floor plans.

The main mass was divided into three functional spaces: offices, manufacturing hall and packing area. Those rectangular forms formulated the interplay of shape grammars – being variously displaced (slid around) in 2-D and 3-D configurations through trial and error sketches to create evacuated outdoors spaces in between for parking, loading docks and planting patios. Those levels were linked through bridges to emphasise the initial prime conceptual form of the cross-section draft sketch. This concept was illustrated in 'x-ray' master plan; where the 2-D projections for all the floors were drawn and overlaid in one conceptual drawing.

Midway through the design process at minute 30.00 exactly, the new condition to design the exhibition hall was introduced. This unpredicted request put the process on deliberate halt and led the architect to rethink the whole design situation and assess the prime concept. Following this imposition, three interim sketches were designed 'reframing' the preceding decisions; the division of functions into separate longitudinal masses, and the idea creating overlap connections between every two masses remained.

Sketch SK(3-1) at node 35 presented a diagrammatic concept for interlocking masses for the first time, while sketches SK(3-2) and SK(3-3) provided 3-D illustrations that reflected an architectural form for overlapping, displacing masses on different floor levels. This stage ended with producing a detailed 3-D *axonometric* sketch.

The final concept merged between two preceding concepts, one that was articulated at node 26 (before imposing the additional request) and another that was iterated at node 35 (after the imposition). In her retrospective comments, the architect reported on the *unfamiliarity* of the design programme of the cheese factory, i.e. difficulty with technical information. This led to abstracting the design outcomes; the master plan did not contain clear indication for the pasteurisation, purification and packaging lines but instead provided conceptual zoning between the interrelated functions.[81] Figure 7.3 illustrates captions and snapshots for the interim and final products for this design experiment.

[81] See Appendix 7.1 to review the *transcription* and *coding* processes for this experiment in addition to the architect's retrospective comments explaining the concept through the products.

7.3.2 Description and Qualitative Analysis

In this design process, the emergence of creative ideas was restricted to the instructions provided in the design brief. Three design actions are identified as creative insights bringing a variety of conceptual ideas and forms to the design discourse. Actions 10 and 14 occurred at the stage of *concept initiation* throughout the self-articulation and analysis on the given information of site-plot. Design action 26 is quite different from the rest. It emerged during an intermediate stage to generate design alternatives for the spatial configuration and for creating possible syntheses that support the decision-making process to develop the concept.

At action 10, sketch SK(1-3) is a preliminary proposal for the spatial configuration that was framed and outlined considering the following aspects: the directions for feeding the raw material in and taking the products out, and the distribution of functional spaces separated in different masses including the production hall, offices, and utilities. This schema of this functional zoning was formulated at this node reflecting the designer's perception of what was required in the design programme.

At action 14, sketch SK(1-4) is a schema for the cross-section conceptual idea proposing splitting functions between vertical floors. This concept was extended to create a preliminary study for the indirect lighting and placing the offices overlooking the main production hall, although, this idea was not clearly emphasised through the following sketches of floor plans: SK(2-1), SK(2-2), SK(2-3), and SK(2-4). The concept of creating three rectangular separated forms became slightly vague during the following attempts to develop alternatives for the spatial configuration.

At action 26, sketch SK(2-5) outlines the configuration of three rectangular shapes again, recalling action 14 but with advanced articulation. Those three shapes were placed in horizontal axes alongside each other creating spaces for vegetation, greenery, docks and parking areas. This kind of spatial configuration was considered as novel in comparison with the prevalent flow of the preceding actions.

At action 35, after the imposition of constraint (node 34), sketch SK(3-1) outlines the concept of creating interlocking masses, an idea emerging for the first time and from which the final design product proceeds. It has a direct relation with action 26 – creating separate longitudinal masses for different functions – but the concept of overlapping those masses was new. A decision was made to locate the exhibition hall at one of the main masses.

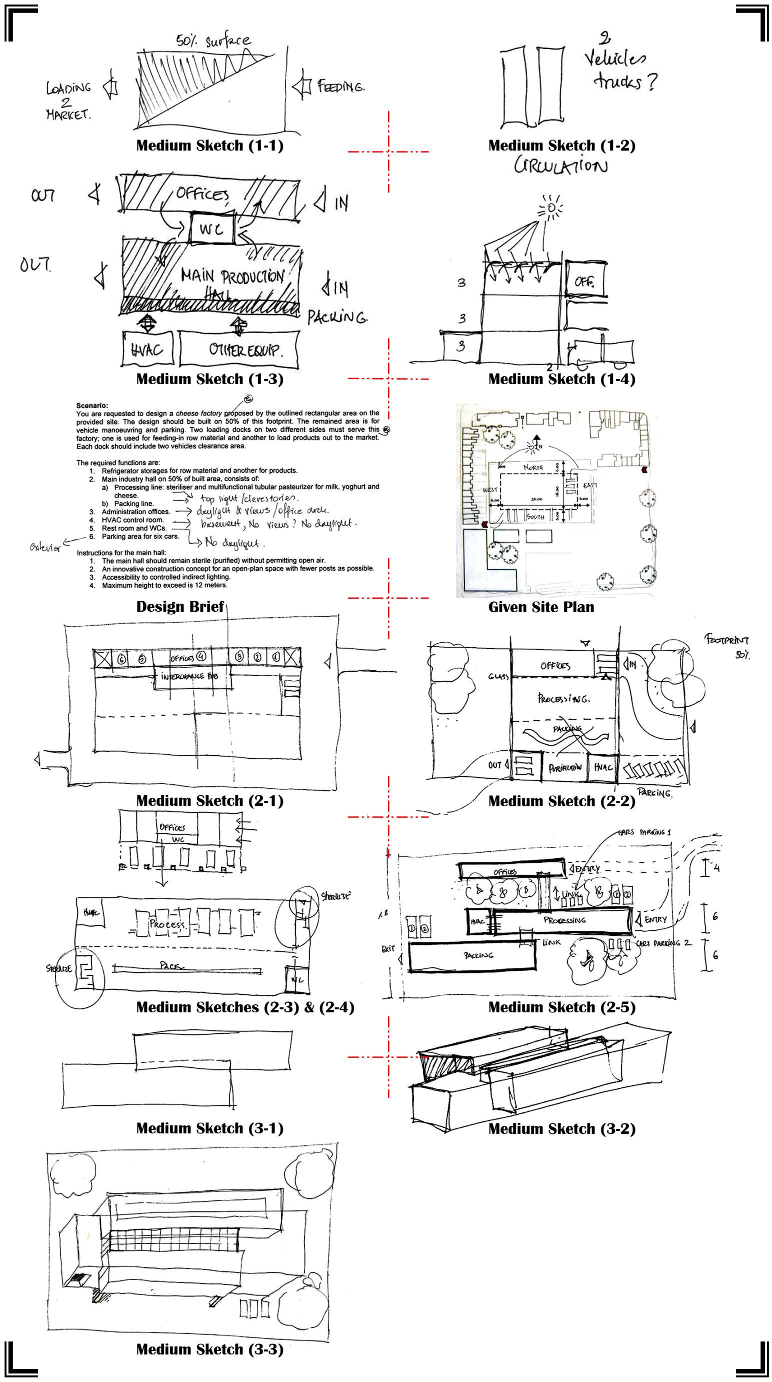


Figure 7.3 Interim artefacts and final products (Case Study 2, Designer 1)

7.3.3 Impact of Imposing External Constraint

- On Design Reasoning

After the request for an exhibition hall to be included in the final design outcome, the process was hence directed to frame the solution by building syntheses between the preceding concepts. Suddenly, the idea at action 35 occurred: to place the two overlapping rectangular forms oppositely in the 'X' axis. The sketched diagram at action 35 reflects an attempt to create overlapping masses in horizontal and vertical levels to frame the final conceptual idea.

This idea merges two concepts: the first is *horizontal displacement*, which was already articulated at action 26 for a conceptual master plan. The second is *interlocking forms* to be partially overlapped, creating zones for vertical elements (i.e. staircases and elevators). This conceptual synthesis is at first introduced in the prevailing paradigm, advancing the initial concept to explore new dimensions of *lateral transformation*. Figure 7.4 illustrates the transformation all through the process, while Figures 7.5 and 7.6 illustrate the sketches overlaying the linkography networks.

We conclude from this outcome that the late imposition of the external request motivated the architect to generate a novel solution by creating synthesis between what was already initiated at the early stage and the actions that appear in the intermediate stage.

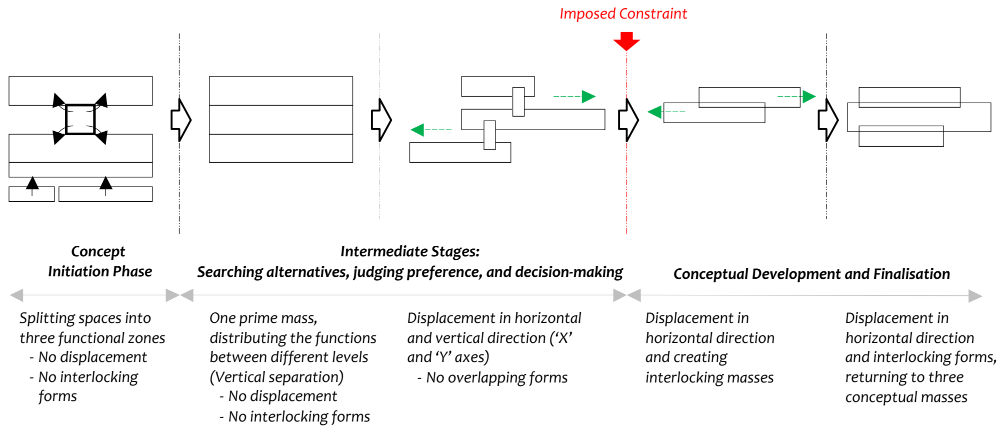


Figure 7.4 Transformation of concept through the spatial configuration of forms (Case Study 2, Designer 1)

- On Transformation of Ideas

Actions 35, 36, and 37 are three interim products emerging after the imposition of the new request to design the exhibition hall. After reading the new brief, a novel idea was introduced to the design discourse at sketch SK(3-1). An abstract concept was presented to centre the final product on, featured as 'overlapping masses'. It was developed and advanced in the following steps; sketch SK(3-2) is a 3-D model for three longitudinal forms interlocked on the main hall, and sketch SK(3-3) is a final axonometric for the whole process.

Interim design products resulting after the imposition of constraint intruded on the process but did not cause drastic change in the primary concept. Rather, the concept was developed to achieve the requested functional purposes as well as the intended architectural composition according to the architect's viewpoint. However, a novel element was added to that conceptual form: creating a composition of interlocking masses was new in this process although it was embarked on during the initial concept. This is considered *lateral transformation* but not a significant paradigm shift.

7.3.4 Correlation with Quantitative Measurements

This section investigates if correlation exists between quantitative and qualitative analyses throughout the events undertaken in this design case. This process comprised four critical actions that are all considered 'transitional' nodes, bridging ideas between preceding and following design media. It was observed that actions 10, 14, 26 and 35 are all media switching nodes. Thus, linking different sketching media to develop the design concept throughout the multiple exchanges of information and the attempts to design several alternatives are all crucial factors that motivated the conceptual development, giving rise to some creative actions. We extend this investigation to include those nodes that deliver significant quantitative measurements within the whole networks of linkograph. Table 7.1 and Figures 7.7, 7.8, 7.9 and 7.10 illustrate the connectivity for the critical nodes; measurements for concatenation; backlink relations; and network analysis respectively. Table 7.2 presents a variety of measurements for this design case.

- Node 10 delivers the maximum integration value.
- Nodes 19 and 26 deliver the maximum t-code identical values.
- Node 16 delivers the minimum t-code value.
- Node 4 delivers the minimum integration value.
- Nodes 1 (design brief) and 26 are the highly connected nodes; *connectivity* values are: node 1 equals 15 (0 backlink and 15 forelinks) and node 26 equals 14 (6 backlinks and 8 forelinks).

At action 1, reading the design brief, it is the most connected node in the whole system with 15 *forelinks*. It reflects the extent to which the concept initiation phase is structured by the design programme. This node delivers high integration value of 2.97 that reflects a shallow network of relations. Concatenated strings of information deliver high t-code values compared to the overall system: t-complexity 10.75 (taugs), and t-entropy 0.86 (bits/char); reflecting the high diversity of characters of binary patterns for the extracted strings.

At action 4, the designer responded to solve a functional element, the mechanical installation for central air conditioning. This node, however, is weakly connected with one *backlink* only. It delivers the minimum integration value on balance to the whole system with value of 0.76 that reflects deep network of relations. Concatenated strings of information deliver relatively low t-code values: t-complexity 7.09 (taugs), and t-entropy 0.46 (bits/char).

At Node 10 is the first attempt to transfer the functional programme into a zoning diagram design sketch SK(1-3). This diagram emphasised the concept of having certain division masses for the main functional spaces; the main production hall, offices, and utilities. Moreover, it presented a study for 'vehicle circulation' feeding in material and exporting out products from the factory. This concept remained throughout the flow of designing until the end of process. It was recalled several times, at nodes 13, 17, 18, 19, 22, 23 and 26, sketches SK(1-3), site plan, SK(2-1), SK(2-2), SK(2-3), SK(2-4), and SK(2-5) respectively. Thus, it is considered *pivotal* in the linkograph in terms of transferring information throughout the design process. This node is connected with 10 links (3 *backlinks* and 7 *forelinks*). It delivers the maximum integration value within the whole network, with a value of 3.15 that reflects a shallow network of relations. Concatenated strings of information for this node deliver high t-code measures in relation to the overall system: t-complexity 10.17 (taugs) and t-entropy 0.79 (bits/char). High integration value means that this action was developed on a series of incremental events that are deeply structured within the whole system.

At action 14, a conceptual idea suddenly occurred and was drawn. The concept of cross-section sketch SK(1-4) is to create one universal space for the main manufacturing hall and to separate the administration offices vertically. This idea was retrieved from memory and recalled several times while developing the floor plans: nodes 18, 19, 22, and 23; sketches SK(2-1), SK(2-2), SK(2-3), SK(2-4). It was recalled to solve the *imposed constraint* and produce the final outcome of this design process, at node 36; sketch SK(3-2). This node is connected with 9 links (4 *backlinks* and 5 *forelinks*). It delivers a relatively high value of 2.73, which reflects a shallow network of relations. Concatenated strings of information deliver high t-code measurements – t-complexity 9.81 (taugs) and t-entropy 0.75 (bits/char) – reflecting a highly diverse arrangement for the binary characters composing the set of codes.

At action 16, the 'sun path' diagram is analysed and scribbled on the presented site layout. This node is weakly connected with 2 links only (1 *backlink* and 1 *forelink*). It delivers low integration value 1.55 that reflects a deep network of relations. Concatenated strings of information deliver the lowest t-code measurements – t-complexity 6.39 (taugs) and t-entropy 0.4 (bits/char) – reflecting repetition in the patterns of characters composing the string of codes.

At action 18 is considered critical to the concept development. It is a medium switching node, starting an experimental phase to develop the master floor plan. While searching for alternatives to distribute the functional requirements relevant to the spatial configuration, the architect created synthesis between several conceptual elements (retrieved from the *initial phase*). This action included evaluation and decision-making. This event operated midway through the process and continued until the completion of a fully detailed master plan that congregated those preceding conceptual elements together. It delivers high integration value of 2.59 that reflects a shallow network of relations. Concatenated strings of information deliver high t-code measurements: t-complexity 10.58 (taugs) and t-entropy 0.84 (bits/char).

At action 26, a decision was made to organise the relations between the functional elements; dividing the prime functions into three different separate masses. This was designed in sketching episode SK(2-5). The concept of this sketch is an outcome of accumulative development throughout the sketches SK(2-1), SK(2-2), SK(2-3) and SK(2-4). Embarking on this action, the final products of sketches SK(3-2) and SK(3-3) were conceptualised and finalised. This node is thus highly connected with 14 links (6 *backlinks* and 8 *forelinks*). It delivers high integration value of 2.88 that reflects a shallow network of relations. Concatenated strings of information deliver the highest t-code measures: t-complexity 11.17 (taugs) and t-entropy 0.91 (bits/char). It reflects the highest diversity of the character string of bits of information compared to the other extracted strings of information in the whole linkograph, comprising a high variety of arrangements of the characters for the sets of binary symbols.

At action 35, an insight has emerged to solve the problem of the imposed constraint at node 34. This action supported the prevalent concept (the distribution of functions in three different masses) and created synthesis with another idea; an illustration of shape grammar for interlocking forms. This concept was deployed to design the final sketches SK(3-2) and SK(3-3). This node is, however, weakly connected with three links only (1 *backlink* and 2 *forelinks*). It delivers relatively low integration value of 1.63, which reflects a deep network of relations. Concatenated strings of information deliver median t-code measures: t-complexity 8.39 (taugs) and t-entropy 0.59 (bits/char).

7.3.5 Results and Discussion

The transformation of concept of *form composition* from one phase to another is signified by the spatial configuration of each interim artefact. The initial concept – to create different elongated masses each housing a certain function (manufacturing/production hall, offices/administration, and accompanying utilities) – remained through the process until the end but with modifications.

In the intermediate phase, the horizontal displacement of masses in the 'X' and 'Y' axes created outdoor spaces for greenery, loading docks and parking areas (see Figure 7.4). After the imposition of the new constraint, the concept was modified accordingly through the synthesis with another idea of interlocking/overlapping masses –maintaining the initial concept by separating the main functional spaces vertically and overlaying the masses in the third dimension. The design parti and drawings were modified accordingly, ending with the final product.

Rationalisation of shapes and *familiarity* with the functional programme of the cheese factory are two essential factors that were considered within the qualitative descriptions of this experiment. The structure of reasoning varied through the process, being initiated in insightful thinking then moving to *incremental* and *synthesis* stages.

In the first stage of concept initiation, insights are bound to the information and instructions provided in the design brief, representing taxonomy of transformation of ideas. Node 10 is the first sketching episode articulating the concept by setting out the functional zoning plan, a kind of diagrammatic configuration for the main mass. At action 14, the schema of cross-section configuration is first initiated but extends the concept to a more advanced level. This is a vertical transformation of the initial concept through a different 3D projection drawing.

Action 18 is a sketching episode for the master plan that compared the present drawing with the preceding products. In this sketch SK(2-1), the concept of zoning diagram was transferred to a detailed plan that was drawn to scale. Although the initial concept of action 10 was recalled at this action 18, the spatial configuration was grounded via merging the three 'elongated rectangles' into one large mass. A new function was added to link the offices area and the production hall that was not included in the functional requirements programme in the design brief. This action constitutes a vertical transformation on the prime concept.

Design episodes 19, 22, 23, and 24 are chronological sequences of development of the main concept. The initial spatial configuration was advanced and developed adding more details to the functional requirements. These interim products reflect vertical transformation on the same main concept.

Action 26 is a *creative leap*, extending the concept to a profound level, with an emphasis on the concept to create three split masses placed in the 'X' and 'Y' axes. Although this interim product fostered the conceptual form via a new configuration, it was built on the initial concept, providing an alternative (design option) to move the concept on.

This study examines two main positions to reflect the structure of reasoning in this design process: *reframing* versus *restructuring* types of reasoning. Reframing is a structured process with knowledge retrieval and trial-error-correction approaches to designing. Restructuring is concerned with *restructuring* the whole design problem, *redefining* the design situation and *reflecting back* into the design brief. Restructuring the design problem represents paradigm shift, redirecting the process to a different state, provided that a redefinition for the initial set of goals takes place. It is likely that restructuring the problem is an outcome of a sudden mental 'eureka' insight occurring.

Having to achieve the specified functional requirements and predefined goals structured the architect's thinking process with certain conditions to initiate the design concept – a shortcut approach to transferring the design brief into spatial configuration. This was reflected at sketching episodes SK(1-3) and SK(1-4).

The embodiment of functional requirements through a zoning diagram and cross-section arrangement determined the main outlines of the concept. Setting up the functional zoning diagram structured the following process and interim artefacts, extending the concept into an intermediate stage of *searching possible alternatives*, *judging preference*, and *decision-making*. The variety of spatial configurations and design alternatives that were tried out to solve the upcoming problems before and after the imposition of an external constraint reflected the architect's expertise, competent skills and imagination in dealing with this type of highly specified and constrained design brief.

This process was directed to *reframe* the prime concept not to restructure the whole problem – evident through the sketching episodes of master plans: SK(2-1), SK(2-2), SK(2-3) and SK(2-4). This approach has structured the design process and paved the way for the *reflective practice* to take place with the sketching episodes. Being based on certain pivotal actions, this venue is patterned in the linkograph to certain utterances, nodes 6, 7, 10, and 14, which characterised the phase for taking an incremental reasoning form; see Figure 7.6 presenting the linkograph.

In this experiment, reframing the concept with *synthesis* after the imposition of constraint is reflected through modification to the main initial concept to make it work. This is not an explicit form of convergence, however, because that new addition was still unprecedented in the process and had not appeared in the concept initiation phase. The relation between *contents* and *structure of reasoning* took a transformational form in this design process. Starting with the phase of *concept initiation*, the first ideas and scribbles of sketching were embarked on as a mutual exchange of information between the architect's knowledge and the design brief. Unfamiliarity with the technical requirements for the cheese factory drove the architect to think, make judgements and reflect thoughts on the proposed programme. This reflects an explicit form of transformational process between the contents of design and reasoning.

After the imposition of the external constraint, the architect took into account the aim to achieve the mental image of the final product as well as the new request. She managed to be flexible to achieve the initial principles of concept as well as the functional condition. Creating synthesis between the old concept and the new idea (overlapping masses) to accommodate the requested function reflected transformation of the concept. However, the following actions were structured to achieve this synthesis and thus were directed to achieve the new goal. This reflected a hierarchical relation between the contents of design and structure of reasoning in this final phase.

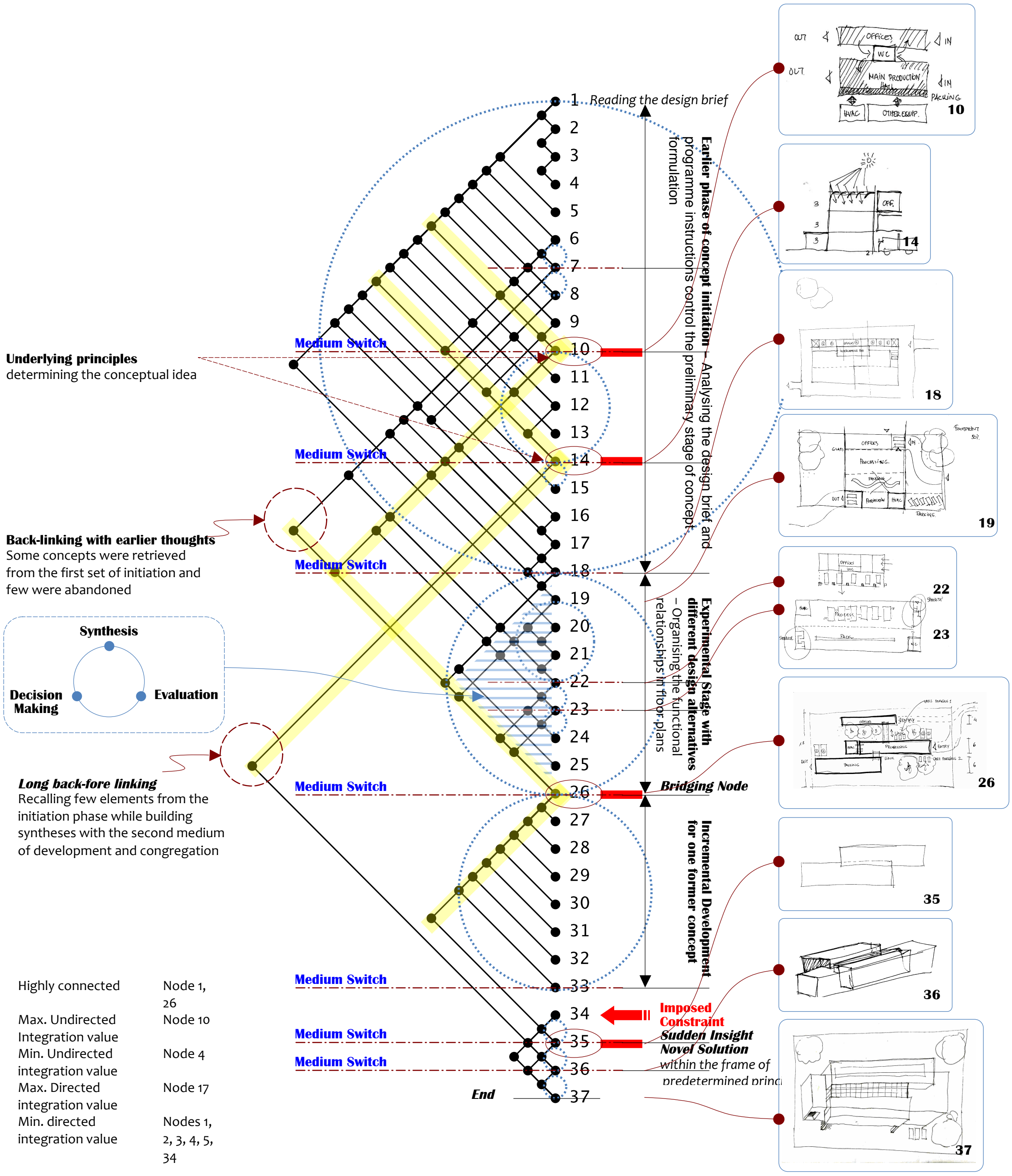


Figure 7.5 Annotation of creative insights, sketching contents, concept transformations via back/forelinking and sketching exchanges (Case Study 2, Designer 1)

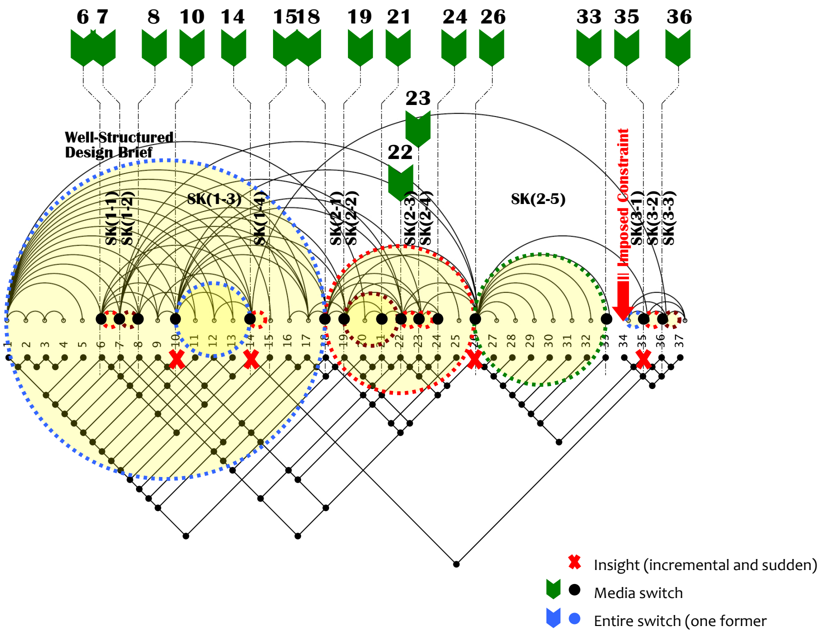


Figure 7.6 Illustration of linkography and archiography media graph overlaid with media switches cutting points and marked up with creative insights (Case Study 2, Designer 1)

Table 7.1 Estimating connectivity values for the transitional nodes, switching media nodes, and significant nodes that achieve the highest or the lowest degrees of integration or t-code measures (Case Study 2, Designer 1)

Type	**Nodes**
Switching nodes	6, 7, 8, 10, 14, 15, 18, 19, 21, 22, 23, 24, 26, 33, 34, 35, 36, and 37
Critical Actions: Sudden flashes Transformation and Paradigm shifts	10, 14, 26 and 35
Significant Quantitative Values	**Nodes**
Highest integration value	Node 4
Lowest integration value	Node 10
Highest t-codes measures	Node 1
Lowest t-codes measures	Node 15
Highest connectivity	Node 1
Lowest connectivity	Nodes 4 {with one link only}

Estimation of Connectivity	**Nodes**	**Backlinks**	**Forelinks**	**∑ Links**
Node 10	{*bk* → 3 / *fore* → 7} = 10 links	3	7	10
Node 14	{bk → 4 / fore → 1} = 5 links	4	1	5
Node 26	{*bk* → 6 / *fore* → 8} = 14 links	6	8	14
Node 35	{*bk* → 1 / *fore* → 2} = 3 links	1	2	3
Node 1	{*bk* → 0 / *fore* → 15} = 15 links	0	15	15
Node 4	{*bk* → 1 / *fore* → 2} = 3 links	1	2	3
Node 16	{*bk* → 1 / *fore* → 2} = 3 links	1	2	3

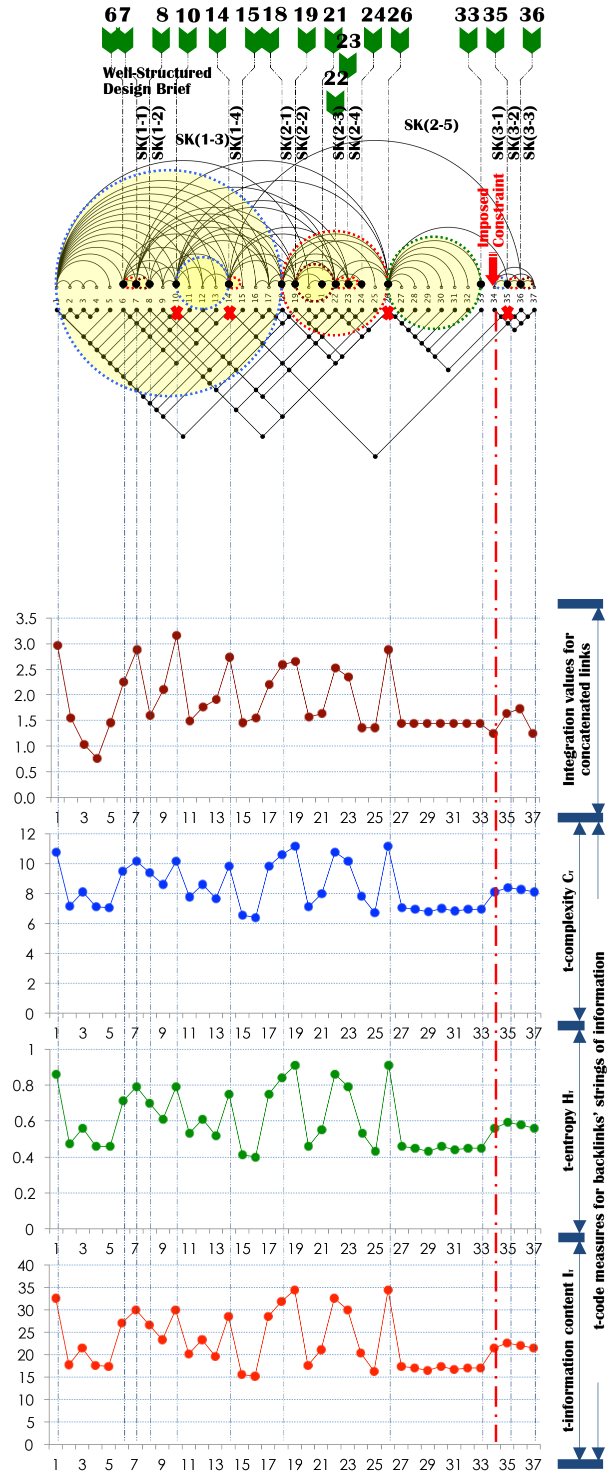


Figure 7.7 Quantitative measures for *concatenated* relations (Case Study 2, Designer 1)

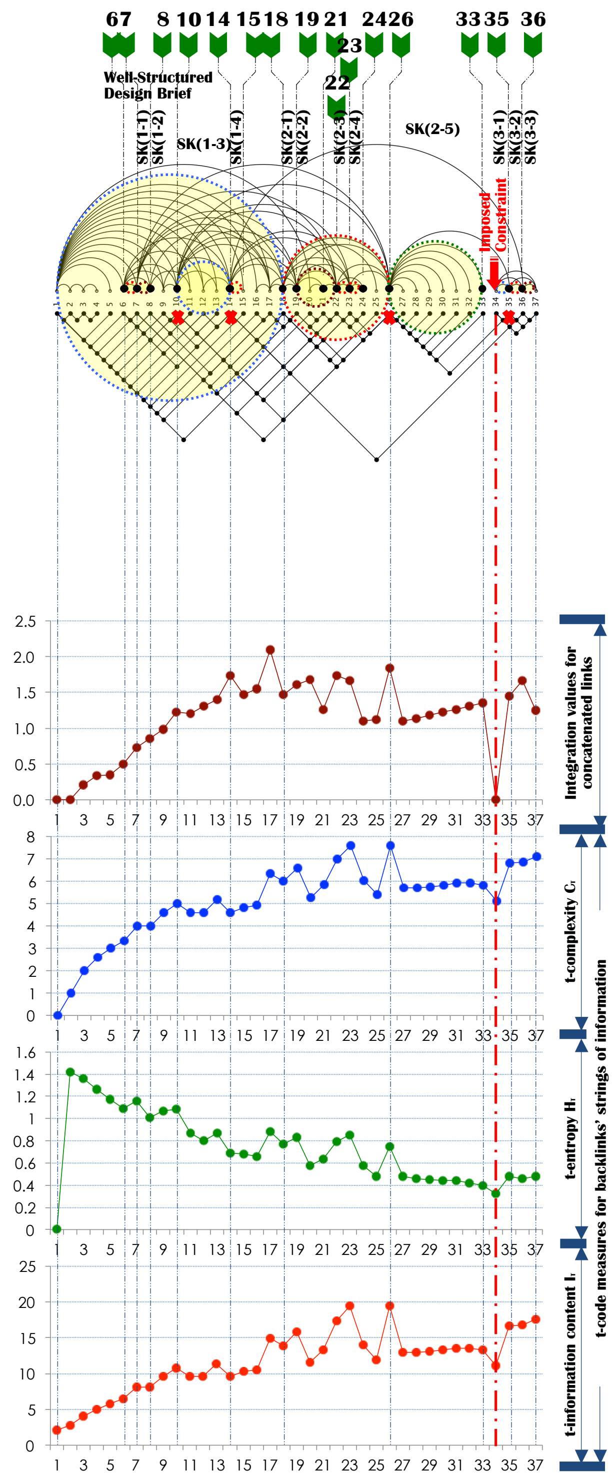


Figure 7.8 Quantitative measures for *backlink–directed* relations (Case Study 2, Designer 1)

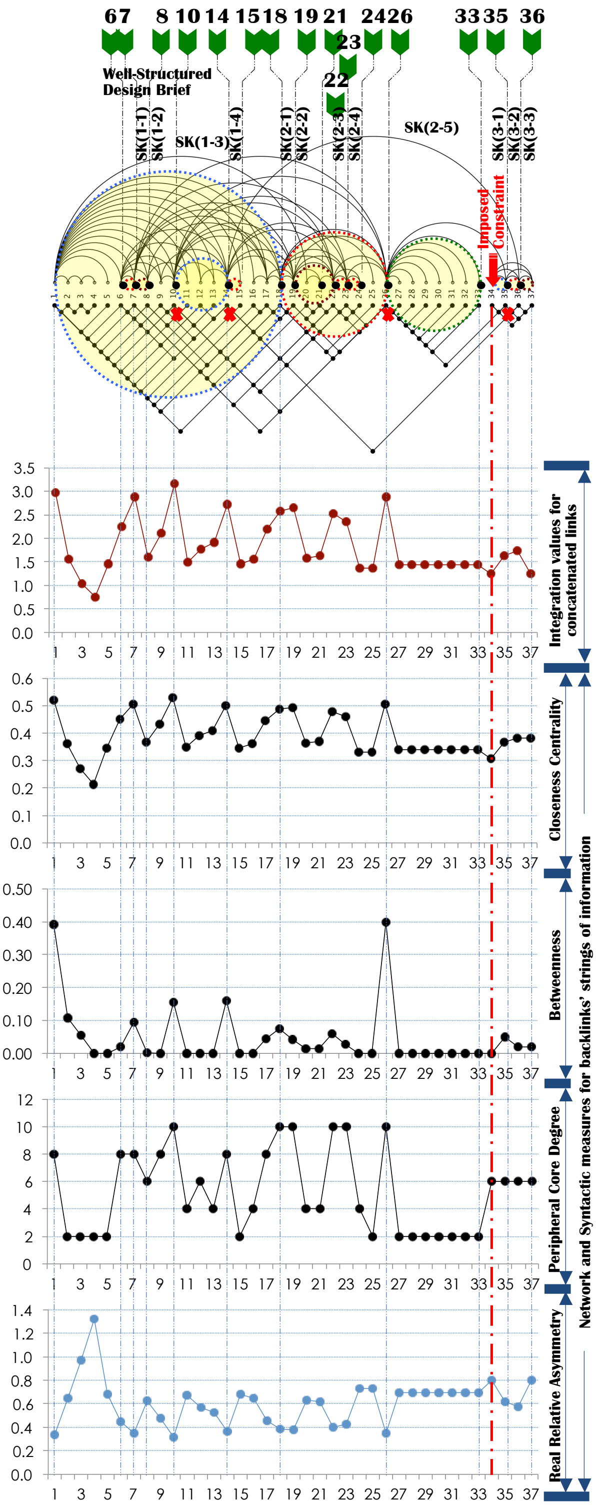


Figure 7.9 Network analysis for *concatenated* relations (Case Study 2, Designer 1)

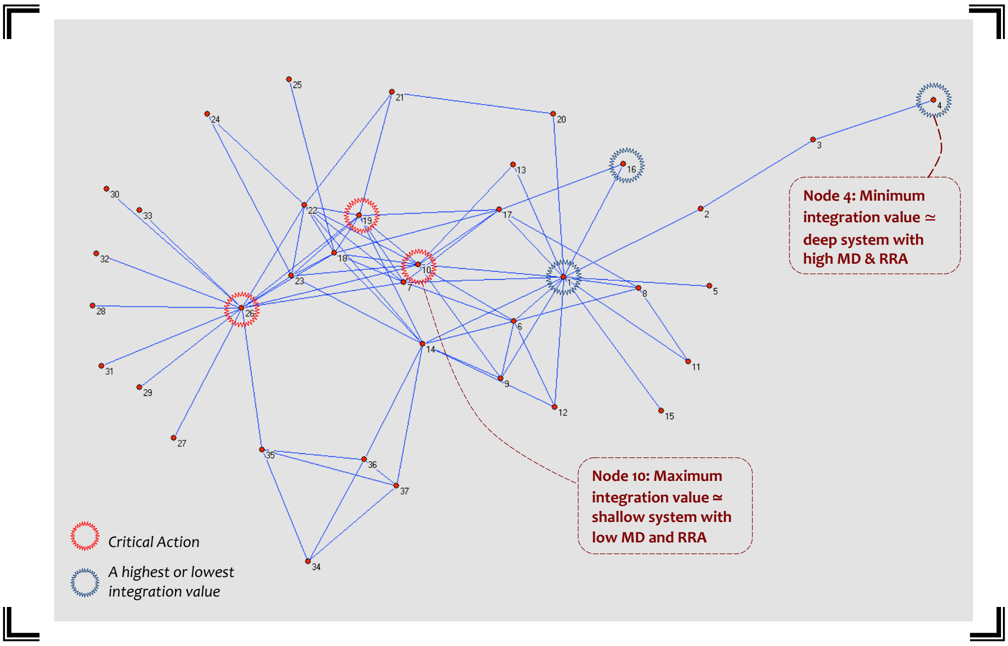


Figure 7.10 Distribution of the strength of integration of nodes in the linkograph (Case Study 2 – Designer 1)

Table 7.2 All the quantitative measurements for the linkograph protocol (Case Study 2, Designer 1)

#	Undirected Measurements								Directed Measurements					
	Closeness Centrality	Betweenness Centrality	Integration	Real Relative Asymmetry (RRA)	Degree Peripheral Core	T-complexity Concatenated strings C_T	T-entropy Concatenated strings H_T	T-info Concatenated strings I_T	Integration – Back Relations	Closeness Centrality – Back Relations	Betweenness Centrality – Back Relations	T-complex – Back strings C_T	T-entropy – Back strings H_T	T-information – Back strings I_T
1	0.52	0.39	2.97	0.34	8.00	10.75	0.86	32.60	0.00	0.00	0.00	0.00	0.00	2.09
2	0.36	0.11	1.55	0.64	2.00	7.13	0.47	17.78	0.00	1.00	0.00	1.00	1.42	2.84
3	0.27	0.06	1.03	0.97	2.00	8.09	0.56	21.38	0.21	0.67	0.00	2.00	1.36	4.08
4	0.21	0.00	0.76	1.32	2.00	7.09	0.46	17.63	0.33	0.50	0.00	2.58	1.26	5.04
5	0.35	0.00	1.46	0.68	2.00	7.04	0.46	17.47	0.35	0.40	0.00	3.00	1.17	5.84
6	0.45	0.02	2.24	0.45	8.00	9.49	0.71	27.09	0.50	0.42	0.00	3.32	1.09	6.51
7	0.51	0.10	2.88	0.35	8.00	10.17	0.79	30.01	0.73	0.46	0.00	4.00	1.16	8.09
8	0.37	0.00	1.60	0.62	6.00	9.39	0.70	26.67	0.86	0.47	0.00	4.00	1.01	8.09
9	0.43	0.00	2.10	0.48	8.00	8.58	0.61	23.34	0.99	0.47	0.00	4.58	1.07	9.62
10	0.53	0.15	3.15	0.32	10.00	10.17	0.79	30.01	1.22	0.50	0.00	5.00	1.08	10.79
11	0.35	0.00	1.48	0.67	4.00	7.75	0.53	20.10	1.21	0.48	0.00	4.58	0.87	9.62
12	0.39	0.00	1.77	0.56	6.00	8.58	0.61	23.34	1.31	0.48	0.00	4.58	0.80	9.62
13	0.41	0.00	1.90	0.53	4.00	7.64	0.52	19.68	1.40	0.48	0.00	5.17	0.87	11.29
14	0.50	0.16	2.73	0.37	8.00	9.81	0.75	28.43	1.73	0.52	0.00	4.58	0.69	9.62
15	0.35	0.00	1.46	0.68	2.00	6.52	0.41	15.64	1.47	0.47	0.00	4.81	0.68	10.24
16	0.36	0.00	1.55	0.64	4.00	6.39	0.40	15.19	1.55	0.47	0.00	4.91	0.66	10.52
17	0.44	0.05	2.19	0.46	8.00	9.83	0.75	28.54	2.09	0.53	0.02	6.32	0.88	14.95
18	0.49	0.07	2.59	0.39	10.00	10.58	0.84	31.84	1.47	0.44	0.01	6.00	0.77	13.88
19	0.49	0.04	2.66	0.38	10.00	11.17	0.91	34.49	1.61	0.45	0.01	6.58	0.83	15.85
20	0.36	0.01	1.58	0.63	4.00	7.09	0.46	17.63	1.67	0.45	0.00	5.25	0.58	11.52
21	0.37	0.01	1.63	0.61	4.00	8.00	0.55	21.04	1.26	0.38	0.01	5.83	0.64	13.34
22	0.48	0.06	2.52	0.40	10.00	10.75	0.86	32.60	1.73	0.45	0.02	7.00	0.79	17.31
23	0.46	0.03	2.35	0.43	10.00	10.17	0.79	30.01	1.67	0.43	0.00	7.58	0.85	19.46
24	0.33	0.00	1.36	0.73	4.00	7.81	0.53	20.30	1.10	0.33	0.00	6.04	0.58	14.03
25	0.33	0.00	1.36	0.73	2.00	6.70	0.43	16.25	1.13	0.33	0.00	5.39	0.48	11.96
26	0.51	0.40	2.88	0.35	10.00	11.17	0.91	34.49	1.84	0.44	0.00	7.58	0.75	19.46
27	0.34	0.00	1.44	0.69	2.00	7.04	0.46	17.47	1.09	0.31	0.00	5.70	0.48	12.92

28	0.34	0.00	1.44	0.69	2.00	6.91	0.45	16.98	1.14	0.32	0.00	5.70	0.46	12.92
29	0.34	0.00	1.44	0.69	2.00	6.75	0.43	16.44	1.18	0.32	0.00	5.75	0.45	13.09
30	0.34	0.00	1.44	0.69	2.00	7.00	0.46	17.31	1.22	0.33	0.00	5.81	0.44	13.26
31	0.34	0.00	1.44	0.69	2.00	6.81	0.44	16.63	1.27	0.33	0.00	5.91	0.44	13.58
32	0.34	0.00	1.44	0.69	2.00	6.91	0.45	16.98	1.31	0.33	0.00	5.91	0.42	13.58
33	0.34	0.00	1.44	0.69	2.00	6.91	0.45	16.98	1.35	0.34	0.00	5.81	0.40	13.26
34	0.31	0.00	1.25	0.80	6.00	8.09	0.56	21.38	0.00	0.00	0.00	5.09	0.32	11.05
35	0.37	0.05	1.63	0.61	6.00	8.39	0.59	22.58	1.45	0.35	0.06	6.81	0.48	16.63
36	0.38	0.02	1.74	0.57	6.00	8.25	0.58	22.01	1.67	0.38	0.04	6.83	0.46	16.72
37	0.38	0.02	1.25	0.80	6.00	8.09	0.56	21.38	1.25	0.38	0.02	7.09	0.48	17.63

Switching medium node
Creative insight
Highest vs. lowest degree of integration or t-code measures

7.4 Designer 2 – Case Study 2 Structured Brief for *Cheese Factory*

7.4.1 Description of Concept Initiation

The phase of concept initiation was centred on the instructions and information provided in the design brief. It is evident that the first rough sketches show a 'structural modular system'. The first sketching episode included analysis for the structure system, services core, vertical elements (staircases and elevators) and vehicle movement (into/out of the site). Studying the functional relations between manufacturing hall and storage, production line and packing, entrances and developing various proposals (1 and 2) at the early phase of concept initiation were all guided by the functional programme in the design brief.

In the intermediate phase, proposals 1 and 2 were synthesised together creating a hybrid proposal. The concept of proposal 3 is to create a large orthogonal mass for the manufacturing hall over the utilities' podium (storage, loading docks and staircases). In this phase the primary conceptual elements were determined, from which the design process would be structured in the following phases. This proposal was developed through a sequence of designing events and sketching episodes, in which the solution transferred from one sketch to another by using a tracing sheet and tracing over the master plan and front elevation. At the end of this phase, the concept was represented through a 3-D perspective that reflected a metaphorical reference to the factory; the idea of 'slices of cheese' inspired designing the main façade clad with metal strips.[82]

The imposition of new constraints midway through the design process caused *fixation* and *disruption* effects that continued for a while; see contents of actions 43–60. The architect struggled to solve the problem of the requested products exhibition hall within the existing design configuration. At first, the main idea was to attach the exhibition hall to the side of the main mass. It was distinguished by taking a different shape; the main mass was orthogonal and the exhibition hall was cylindrical.

Another proposal overcame the fixation effect with a solution that included the exhibition hall within the main configuration. According to this solution, the area and proportions of the main mass were modified to accommodate the new function. The conceptual form for this proposal is a large mass over the podium and freestanding structural elements to hold the overlaying mass; see the interim products at Figure 7.11 and the transformation of concept at Figure 7.12. Studying the relations between the functional spaces after the newly developed configuration has ended by producing the final master plans. The façade and 3-D perspective were designed according to this concept.

7.4.2 Description and Qualitative Analysis

A variety of critical actions are captured and considered to be creative hinges that act to fortify the development of design concept throughout until the end of the design process: actions 18, 25, 41 and 63. Those actions varied, being incrementally emerging or suddenly occurring in the process.

[82] See Appendix 7.2 to review the *transcription*, *coding* processes and the contents of sketching episodes for this experiment.

Action 16 framed the solution for the master plan and longitudinal section proposals for the factory that were based on incremental development through the preceding events: sketch SK(2-2). This action clustered an idea for 'looped circulation' between the utilities on the ground floor and the main production hall on the upper plan. This proposed solution emphasised two design decisions: (1) creating a central core for the services and staircases; (2) the vertical split between services and production areas (receiving the raw material on the ground floor and sending it to the manufacturing hall in the upper floor plan). Those decisions were elaborated through the preceding events and therefore action 16 is considered incremental and preserving the flow of prevalent concept.

Action 25 presents a novel solution that occurred on the prevailing concept: sketch SK(3-1). In this sketching episode, the zoning diagram for functional requirements and machinery for the manufacturing hall is organised in a way that facilitates a one-way 'zigzag' circulation route. Being served with three feeding 'in/out' elevators, the steriliser machine for production is provided with material from the storage at the ground floor. This concept of zigzag circulation between production and packing has occurred suddenly in the flow of designing without any relation to the preceding actions and thus is considered to be a *sudden creative insight*.

Action 41 presents an analogy to shape the 3-D perspective taking the form of sliced strip-cladding: sketch SK(4-8). This concept was interpreted during the architect's retrospective comments after the process as a subjective interpretation of the form rather than a functional requirement. It was not developed according to the preceding actions but from imagination of what a cheese factory should look like, the designer commented.

Action 63 focused on presenting a robust solution for the requested exhibition hall, to be attached to the main mass, exposed and held over four pillars – sketch SK(5-6). It preserves the prevalent concept creating one main orthogonal mass carried over a smaller podium for the utilities. This solution provided another architectural treatment for the exhibition hall replacing the previous cylindrical mass and extending the rectangular cantilever of the main building to be held on pillars. This action reflected a decision that was made after experimenting with two different proposals and evaluating each one. It is therefore considered an incremental insight occurring from the preceding events. See Figure 7.11 to review the interim and final products of this design process.

7.4.3 Impact of Imposing External Constraint

- **On Design Reasoning**

At node 42, the new request to add an exhibition hall was imposed and caused a fixation effect that was experienced twice at nodes 43 and 58. It required the architect to rethink the main conceptual elements to solve this new problem. This led the target of the following actions towards prioritising those conceptual elements and to fix the new function space within the existing programme of relations. The 3-D spatial configuration was preserved in the first attempts to evolve a solution.

Attaching a cylindrical shape to the main mass was an attempt to reframe the solution without making too many alterations. Although this concept has transformed with slight changes, this action is considered incremental and dependent on the preceding actions.

After experiencing fixation effect, particularly at actions 43 and 58, another proposal was formulated that reasserted the previous form reframing the solution by merely prolonging the mass to include the exhibition hall held on four freestanding pillars. This modification guided the following designing actions to amend the master plan and elevation to include the added elements. It confirms a hierarchical relation between the contents of design and structure of reasoning to achieve the predefined goal at action 63. The final stage framed the concept with the modification included. A detailed 3-D perspective reframed this concept with different angles shown in abstractly rendered sketches.

- **On Transformation of Ideas**

The first attempt, attaching a cylindrical form to the main mass, reflected lateral transformation: exploring a solution that is different from the preceding one; while the second attempt, extending the main mass to be held over four structural pillars, reflected vertical transformation from the preceding concept (reframing the concept). This attempt was then developed and articulated through the following interim products for the master plan, elevation and 3-D perspective, which also reframed the concept and are considered to be a vertical transformation of the solution.

7.4.4 Correlation with Quantitative Measurements

This section correlates the quantitative measurements of significant actions and the ontology of architecture design and concept development relevant to the interim artefacts emerging at those actions. It tests the structure of the network of relations with the preceding and following actions to reveal the context of emergence of creative actions and sudden shifts. The effect of imposition of a new request midway through the process on the following actions and interim artefacts is investigated.

This process included four creative insights varying between *incremental* and *sudden*, nodes 25, 41 and 63, where all emerged while switching media between two different sketches. Our investigation includes transitional and bridging nodes since linking between different media, developing the concept throughout multiple switches, drawing attempts and sketching episodes are considered prime endeavours giving rise to creative insights and ideas. Creative insights 25, 41 and 63 in addition to node 36 are considered *transitional* nodes bridging certain ideas and conceptual solutions between different sketching media and chunks of thought. Figures 7.15, 7.16, 7.17 and 7.18 illustrate the connectivity for the critical nodes; measurements for concatenation; backlink relations; and network analysis respectively. Table 7.3 presents a variety of measurements for this design case. A variety of actions delivered significant quantitative measures within the whole linkograph, whether high or low values, such as:

- Action 35 delivers the maximum integration value and t-code measures with value 2.42.
- Actions 56 and 80 deliver the minimum integration with values 1.16 and 1.14 respectively.
- Action 31 delivers the minimum t-code measures. It signified knowledge retrieval action when the architect looked back to the brief while switching from one sketch to another: the reappearance of design brief within the designing actions and sketching episodes that acts to structure the design process.
- Actions 1 and 5 are the most connected vertex with connectivity of 12 links. Action 1 equals 0 *backlinks* and 12 *forelinks*; while action 5 equals 3 *backlinks* and 9 *forelinks*. Action 1 was reading the design brief, and action 5 was the first sketch set up to transfer the abstract information into design concept.

Action 1 represents the initiation point for any design process by *reading the design brief* and referring to it as the source of functional programme, requirements and scenario of the project. This medium refers to the design brief, which was recalled at different occasions to retrieve information and structure the design process. It is thus strongly connected with 12 forelinks to nodes 2, 3, 4, 5, 6, 8, 10, 18, 26, 31, 48 and 59 and delivers the maximum connectivity value in the whole linkograph. Visiting the design brief on different occasions acts to structure the process with its predefined set of goals and problems (to specify and solve a detailed functional programme and to decompose the problem into less complex parts to ease generation of solutions). It delivers median integration value 1.77 on balance to the measures of other vertices in the whole linkograph.[83] Concatenated strings of information for this node deliver high t-code measures, with t-complexity 14.21 (taugs) and t-entropy 0.61 (bits/char).

Action 5 delivers (like node 1) the maximum connectivity value compared to the overall linkograph. It is the first depiction of drawing in sketch episode SK(1-1): transferring the abstract information into zoning study plan for the functional elements. This action is connected with 12 links (3 *backlinks* and 9 *forelinks*) and is recalled several times in the following process. It delivers median integration value of 1.81 with median depth and real relative asymmetry. Concatenated strings of information for this node deliver high t-code measures, with t-complexity 13.44 (taugs) and t-entropy 0.56 (bits/char).

[83] Median integration value means that the network of relations at this node is neither 'deep' nor 'shallow' with median mean depth and real relative asymmetry values. Thus, the mean path length Li from this vertex to reach any other vertices in this network using the shortest number of steps possible in each case is neither a 'linear' nor a 'non-linear' sequence of relations.

Action 16 presents a decision to split the utilities core into two halves and create a curved route for the vehicles to pass through. This idea was initiated and developed for a sketching episode SK(1-2) and it was developed from the previous sketch SK(1-1). It was the first proposal explored in this investigatory phase and was recalled to create synthesis with the second proposal at sketching episode SK(2-3) to make the third proposal for the master plan at sketching episode SK(3-1). This node is connected with 9 links (5 *backlinks* and 4 *forelinks*). It delivers median integration value of 1.93 with median depth and real relative asymmetry. Concatenated strings of information deliver high t-code measures, with t-complexity 13.46 (taugs) and t-entropy 0.56 (bits/char).

Action 25 is a critical action in advancing the conceptual idea to a meaning solution. This creative insight creating a 'zigzag' route of circulation emerged suddenly in the flow of sketching of sketch SK(3-1). This idea was recalled at sketching episodes SK(4-3) and SK(6-2), at actions 36 and 69 respectively, for the incremental development of the master plan. It integrates the relation between the utilities and storage areas at the ground floor as well as the manufacturing hall at the first floor. This action is connected with 10 links (3 *backlinks* and 7 *forelinks*). It delivers relatively high integration value 2.10 for shallow network of relations. Concatenated strings of information deliver high t-code measures, with t-complexity 13.17 (taugs) and t-entropy 0.54 (bits/char).

Action 31 delivers the lowest t-code measures in the overall system. At this action, the designer glanced back at the design brief to retrieve information on the functional requirement. It is weakly connected with two links (1 *backlink* and 1 *forelink*). It delivers low integration value 1.36 for a deeply structured network of relations. However, the extracted string of information for this node consists of a repetitive pattern of '0' symbols that reflects low complexity for the overall composition. Thus, it delivers the lowest t-codes, with t-complexity 7.61 (taugs) and t-entropy 0.24 (bits/char).

Action 35 is the start of sketching episode SK(4-2), which replicated the concept of a previous sketch, tracing over sketch SK(4-1). It does not reflect a significant creative movement, though it delivers the highest integration value in the whole linkograph of value 2.42 for a shallow network of relations. It is highly connected with 9 links (3 *backlinks* and 6 *forelinks*), most of which are connected with certain spatial elements while tracing over sketch SK(4-1). Concatenated strings of information deliver the maximum t-code measures in the overall system; delivering t-complexity 14.58 (taugs) and t-entropy 0.63 (bits/char).[84] High t-code measures reflect the diversity of arrangement in the extracted string of information that reveal the complexity of relations between action 35 and the rest of the actions in the linkograph.

Action 41 presents the metaphor using stripped cladding to render the external facades of the factory while designing the 3-D perspective of sketching episode SK(4-8). This idea was recalled again at sketching episode SK(7-2), at action 76, responding to the ontology of the 3-D concept development. This node is connected by 6 links (4 *backlinks* and 2 *forelinks*). It delivers median integration 1.71 and real relative asymmetry values average to all measures. This sub-system of relations is neither shallow nor deep. Concatenated strings of information for this node deliver median t-code measures, with t-complexity 10.13 (taugs) and t-entropy 0.37 (bits/char).

Action 56 represents a comment by the designer on sketch SK(5-2) after imposing the new constraint requesting the 'exhibition hall' to be included within the functional programme. This comment was: 'I want to set up a permanent solution but apparently not different at all.' This decision shows perseverance in slightly transforming the prime concept to include the new request, without restructuring the entire solution. It signifies an incremental process of reasoning to structure the following actions and interim artefacts on the primary concept. It is weakly connected with 2 *backlinks* only. Thus, it delivers low integration value 1.16 for a deeply structured network of relations. Concatenated strings of information deliver low t-code measures, with t-complexity 9.23 (taugs) and t-entropy 0.32 (bits/char).

[84] Notice that this action 35 delivers maximum value for integration (depth measure) as well as for t-code deterministic information measures. High integration exists when the network of relations is shallow with low mean depth and real relative asymmetry values. This means that the mean path length Li to move from this vertex to reach any other vertices in the network using the shortest number of steps possible in each case is a linear sequence of relations. Few steps are required to reach the end side of the system. As proved in Chapter 5, integration (depth) measure correlates with t-code measures in 'shallow' networks.

Action 63 is a creative action that frames the concept solution for the imposed constraint of sketching episode SK(5-6). At this action, a 3-D perspective for the exhibition hall was designed and attached to the main mass (upper floor of the factory hall) and overlaid over four freestanding pillars. This idea was recalled and responded to the development of the final 3-D perspective at the sketching episodes SK(6-3), SK(7-1), SK(7-2), SK(7-3) and SK(7-4), at actions 73, 75, 76, 77 and 79 respectively. It was slightly modified. This action is connected with 10 links (4 *backlinks* and 6 *forelinks*). It delivers median integration 1.71 with median depth and real relative asymmetry. This sub-system of relations is neither shallow nor deep. Concatenated strings of information for this node deliver high t-code measures, with t-complexity 13.55 (taugs) and t-entropy 0.57 (bits/char).

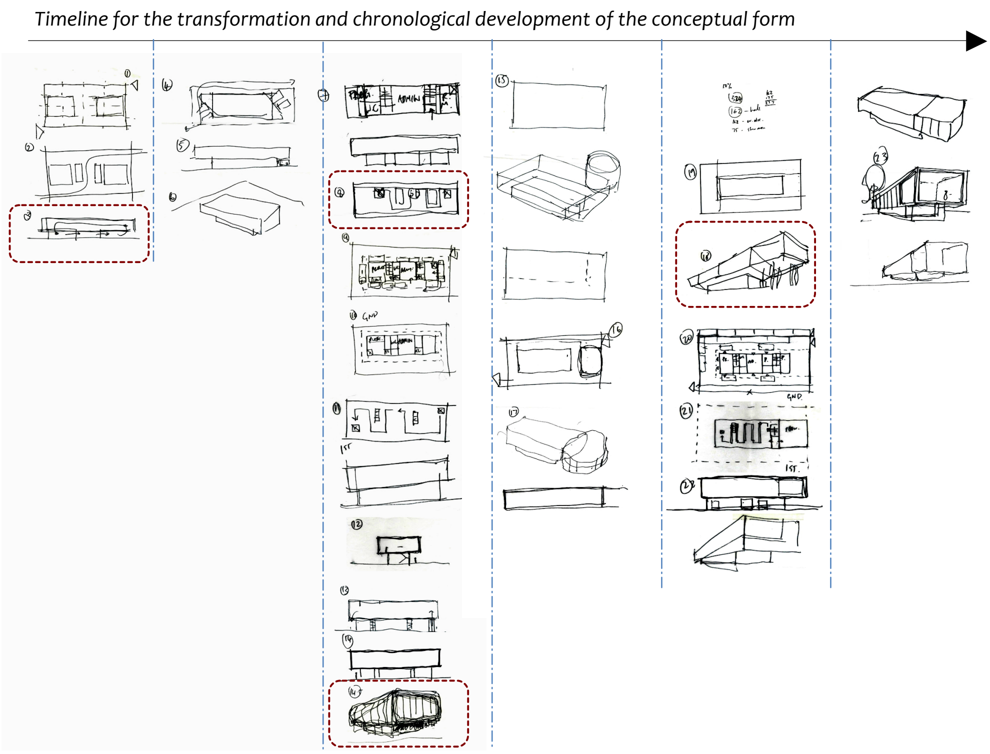


Figure 7.11 Interim artefacts signify multiple proposals (Case Study 2, Designer 2)

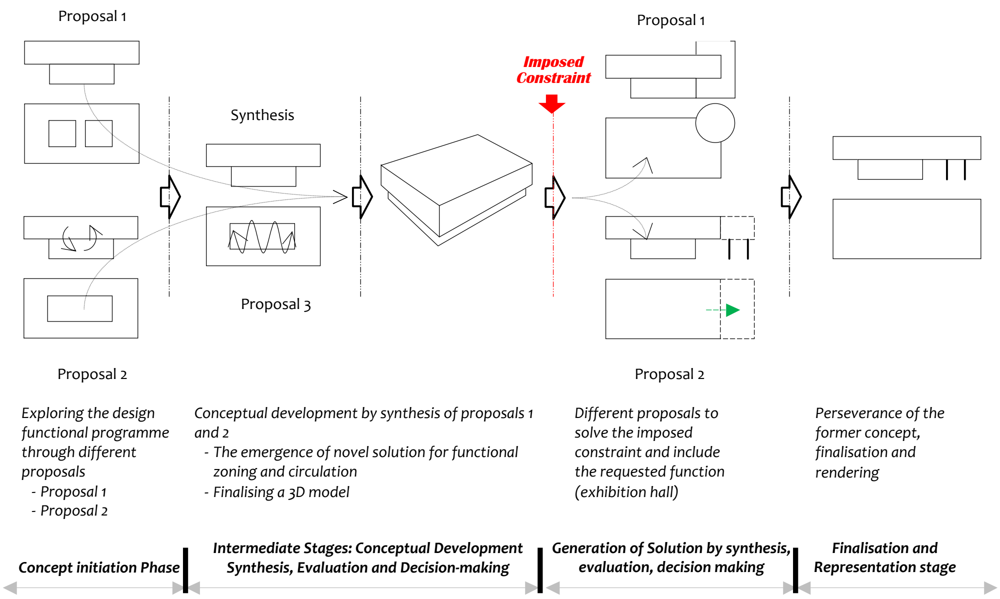


Figure 7.12 Transformation of concept through the spatial configuration of forms (Case Study 2, Designer 2)

7.4.5 Results and Discussion

The threshold of this process was inspired by the design brief and instructions. The functional programme played a vital role in structuring the first notions to initiate the design concept and to achieve the set of requirements and goals. This early stage of conceptualisation reflects the *hierarchical* relation between the contents and structure of reasoning, basically directed by the design brief.

Two proposals were presented in this initiation stage illustrating one prime concept for vehicle circulation and the processes of 'feeding-in' raw material and 'outlet for production'. Proposal 2 is a development of proposal 1. Reframing the initial concept in proposal 2 assures the *vertical transformation* type that was articulated in Goel's definition (1995), i.e. the perseverance of a central core of utilities in both proposals showed this vertical transformation providing the concept with more details – resumed from actions 5 to 24 providing drawings for the master plan and section-elevation.

A third proposal provided a novel solution to solve the 'processing line' in relation to the split between two cores of utilities, providing the zigzag arrangement for the machinery and equipment at action 25. Although this solution was introduced to the same *concept of form*, it appeared suddenly and changed the whole configuration of the first floor plan. *Synthesis* between proposals 1 and 2 sustained the conceptual form; one exposed mass over a podium of services. In the intermediate phase, the concept of proposal 3 was reframed and developed through some actions for adding details and analysing the main functions and zoning relationships. The relation between the *contents* of those actions and the *structure of reasoning* is hierarchal in order to achieve the set of goals that were defined at proposal 3. This phase ended by producing detailed 3-D perspective at action 41.

The structure of reasoning of this process wavered between *reframing* the solution and *restructuring* the design problem. Both approaches generated a variety of solutions throughout the process. The variation of modes of reasoning has affected emergence of solutions as either *incremental* or *sudden*. However, the lengthy stages of *reframing* the prime concept dominated the process. This is reflected through the intensive development and drafting of solutions that preserved the concept of forms and solutions for the interim artefacts of master plans, sections and 3-D perspectives.

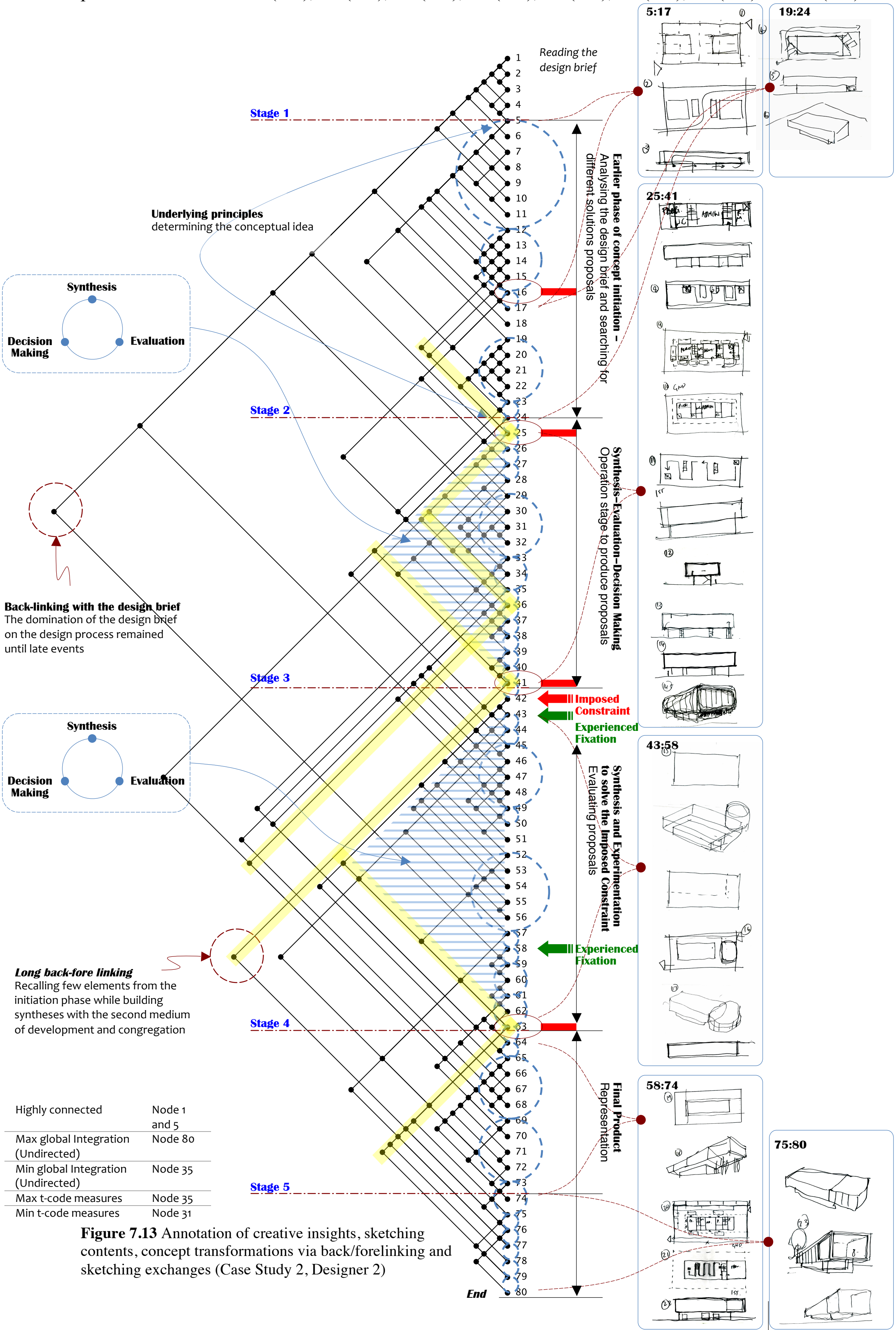
The great number of interim products distinguishes this design experiment: 32 artefacts were designed in the process that aimed to explore and examine different aspects of this technical project. The *reflections-in-action* with the products enabled the process to reach profound levels to examine all the functional possibilities for the zoning and spatial configurations.

Most decisions were taken to frame the prevailing concept while exploring and evaluating different proposals for the utilities core, circulation, production line, arrangement of machinery, feed-in and outlets. Sketches SK(1-1), SK(2-1) and SK(2-2) of proposal 1, at actions 5–17, represented the basic conceptual elements for the design. Sketches SK(2-3), SK(2-4) and SK(2-5), at actions 19–24, reframed the concept and provided more details.

However, the formation of proposal 3 and sudden occurrence of the zigzag configuration rearranged the production line entirely (rearranging the manufacturing apparatuses). It restructured the problem of the master plan in a different way from the preceding proposals within the primary spatial envelope. This action directed the following interim artefacts to achieve its goal and controlled the process to promote the study of functional zoning at a profound level. Therefore, sketches SK(3-1), SK(3-2) and SK(3-3), at actions 25–32, are considered pivotal actions that structured the process and elaborated the development of concept and final products. This was addressed in the linkography annotation as the *operational zone* (see Figures 7.13 and 7.14).

The intermediate operational zone continuing from actions 33 to 40 reflected the architect's attempt to re-sketch and emphasise the solution by detailing the master plan, solving the functional requirements with further studies. Overlaying sheets and tracing over preceding sketching episodes shows the interrelation between the interim outcomes. The primary concept of the zigzag configuration and spatial composition was reasserted in the sketching episodes SK(4-3), SK(4-4) and SK(4-5), at actions 36–38, which showed perseverance in reframing the prevailing flow.

The imposition of external constraint at action 42 controlled the design process and emphasised the hierarchical relation between the contents and structure of reasoning until the end of the process. Although causing disruption from actions 43 to 63, the final stages framed the solution through a series of products at sketches SK(5-6), SK(6-1), SK(6-2), SK(6-3), SK(7-1), SK(7-2), SK(7-3) and SK(7-4).



Highly connected	Node 1 and 5
Max global Integration (Undirected)	Node 80
Min global Integration (Undirected)	Node 35
Max t-code measures	Node 35
Min t-code measures	Node 31

Figure 7.13 Annotation of creative insights, sketching contents, concept transformations via back/forelinking and sketching exchanges (Case Study 2, Designer 2)

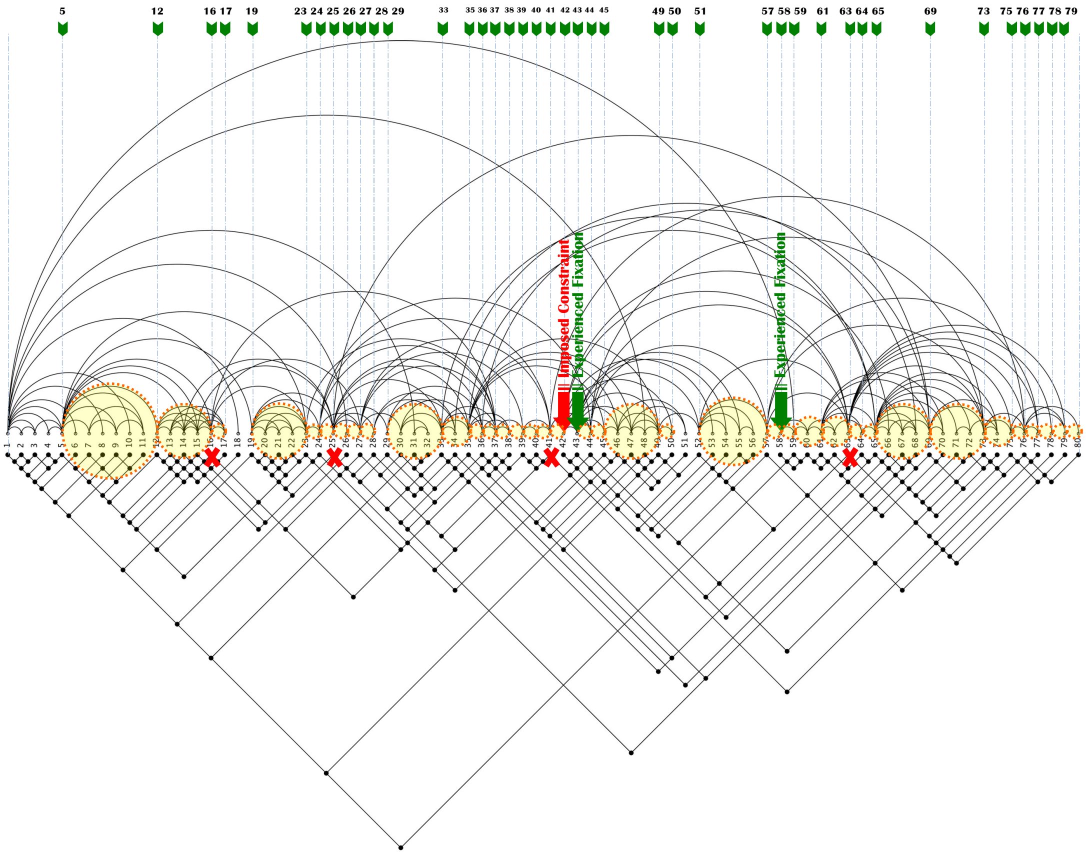


Figure 7.14 Linkography protocol of the design process (Case Study 2, Designer 2)

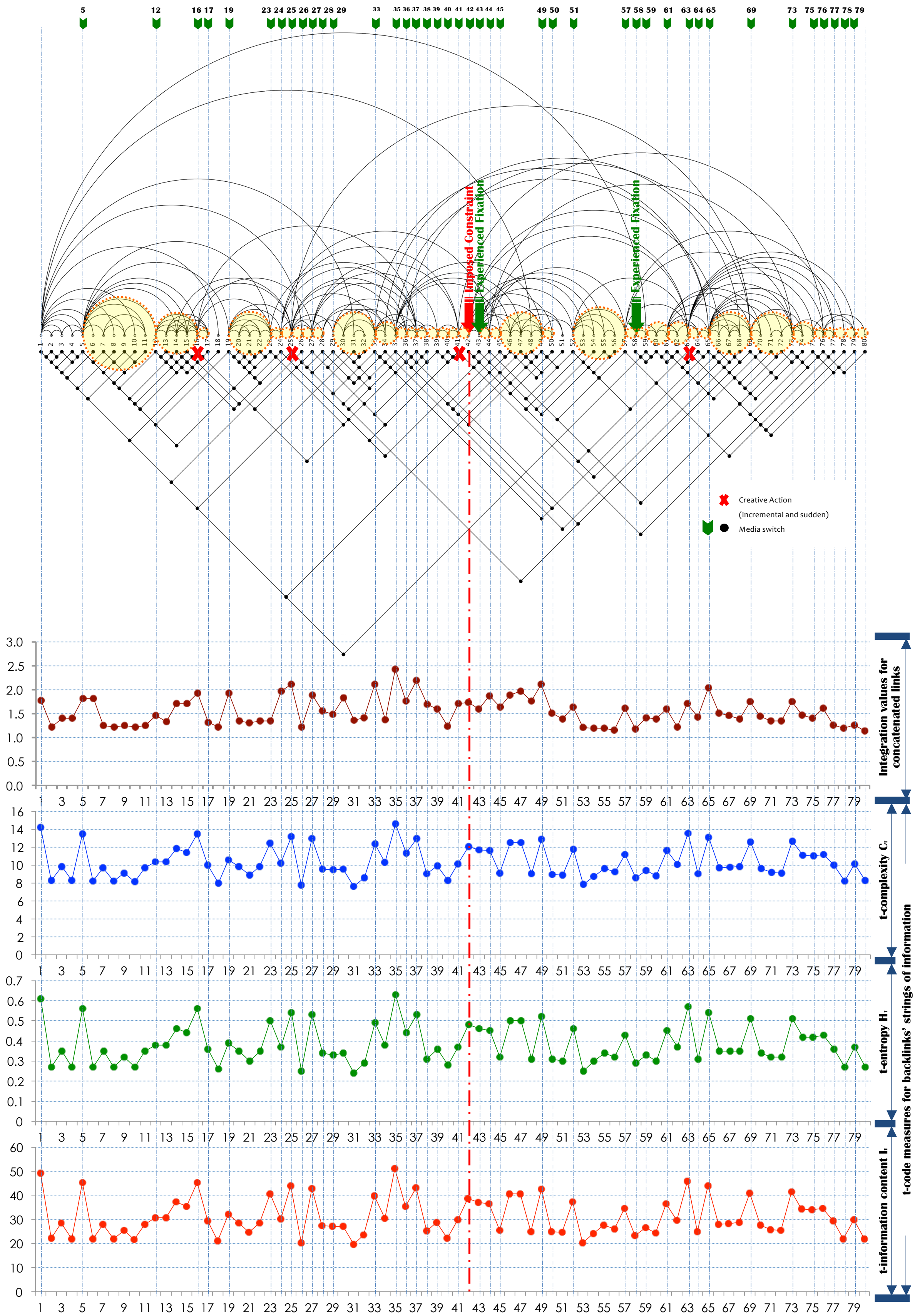


Figure 7.15 Quantitative measures for *concatenated* relations (Case Study 2, Designer 2)

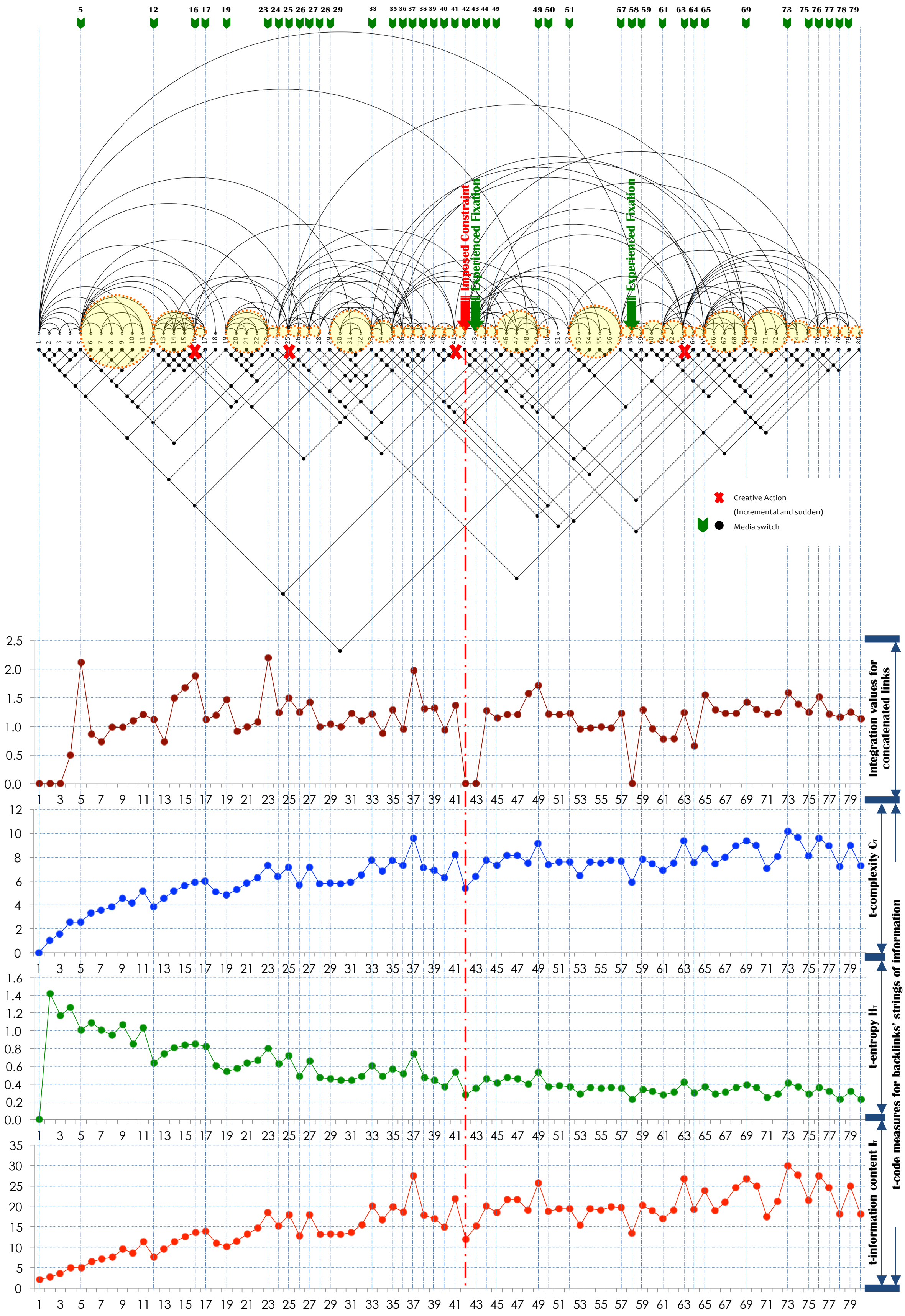


Figure 7.16 Quantitative measures for *backlink-directed* relations (Case Study 2, Designer 2)

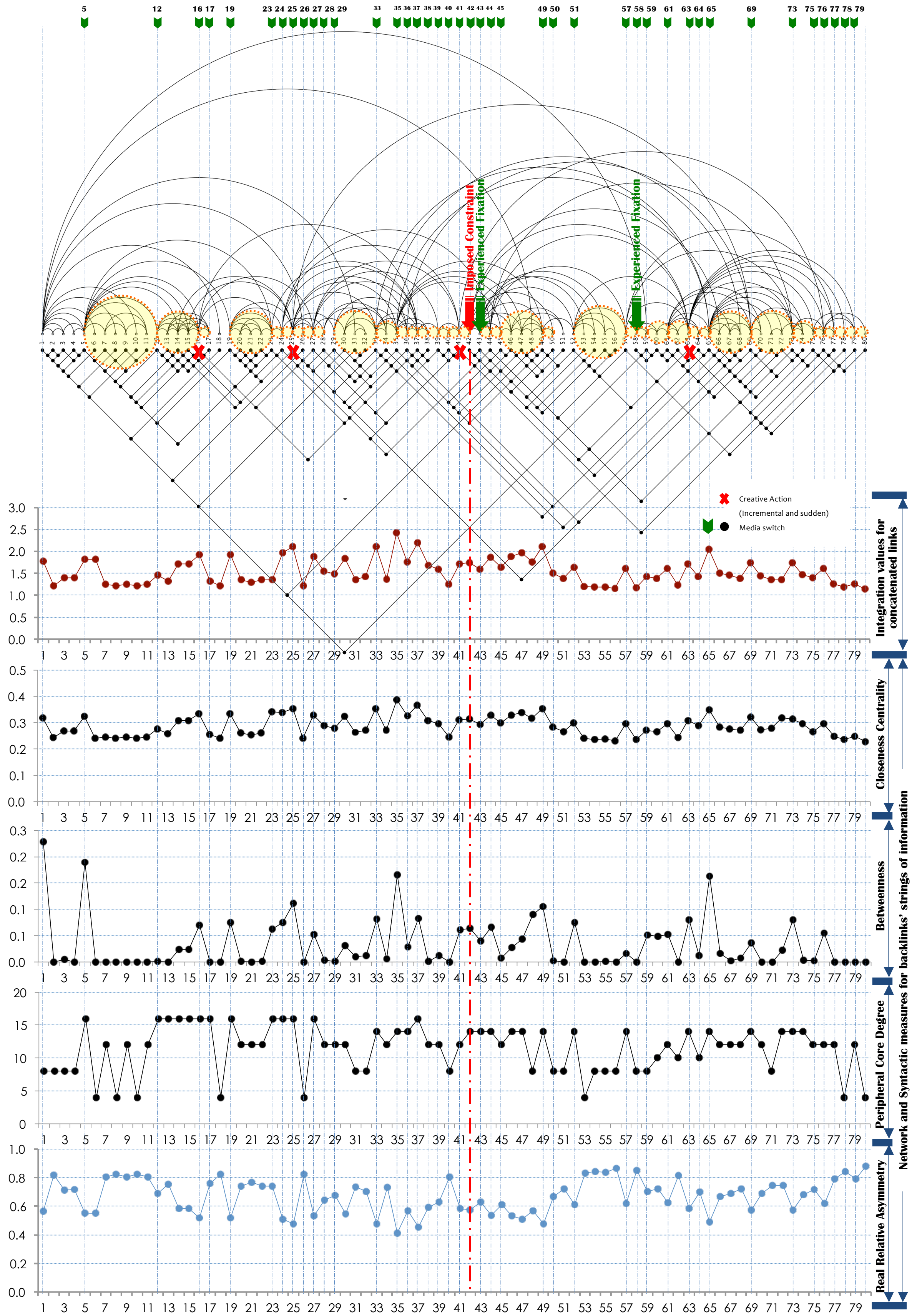


Figure 7.17 Network analysis for *concatenated* relations (Case Study 2, Designer 2)

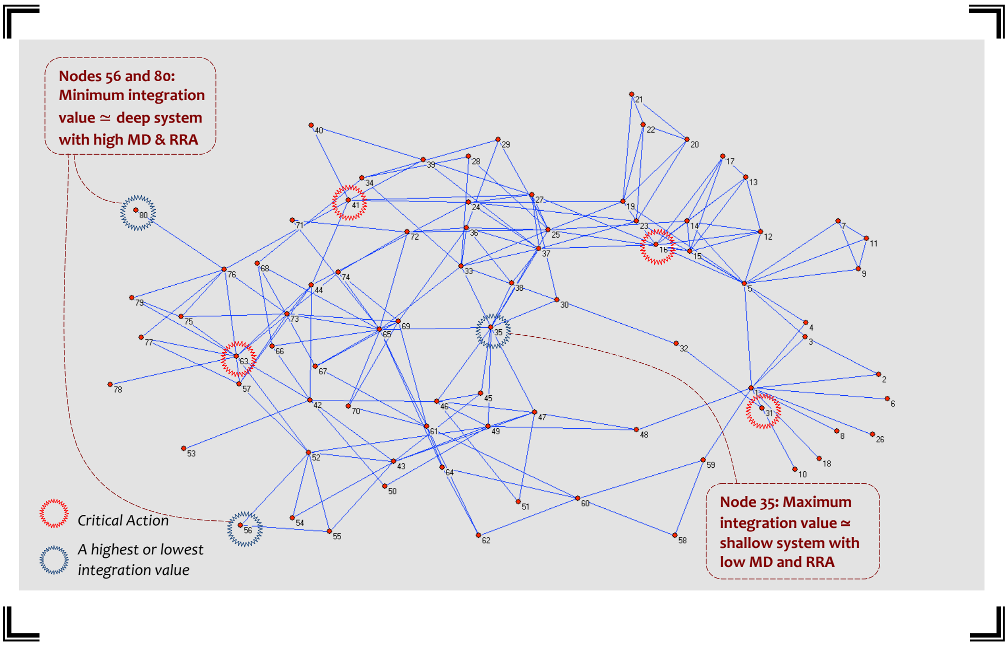


Figure 7.18 Distribution of the strength of integration of nodes in the linkograph (Case Study 2, Designer 2)

Table 7.3 All the quantitative measurements for the linkograph protocol (Case Study 2, Designer 2)

#	Undirected Measurements								Directed Measurements					
	Closeness Centrality	Betweenness Centrality	Integration	Real Relative Asymmetry (RRA)	Degree Peripheral Core	T-complexity Concatenated strings C_T	T-entropy Concatenated strings H_T	T-info Concatenated strings I_T	Integration – Back Relations	Closeness Centrality – Back Relations	Betweenness Centrality – Back Relations	T-complex – Back strings C_T	T-entropy – Back strings H_T	T-information – Back strings I_T
1	0.32	0.23	1.77	0.56	8	14.21	0.61	49.24	0.00	0.00	0.00	0.00	0.00	2.09
2	0.24	0.00	1.22	0.82	8	8.29	0.27	22.15	0.00	1.00	0.00	1.00	1.42	2.84
3	0.27	0.00	1.40	0.71	8	9.83	0.35	28.54	0.00	1.00	0.00	1.58	1.17	3.50
4	0.27	0.00	1.40	0.72	8	8.25	0.27	22.01	0.50	0.60	0.00	2.58	1.26	5.04
5	0.32	0.19	1.81	0.55	16	13.44	0.56	45.36	2.11	0.80	0.08	2.58	1.01	5.04
6	0.24	0.00	1.81	0.55	4	8.23	0.27	21.93	0.87	0.56	0.00	3.32	1.09	6.51
7	0.25	0.00	1.25	0.80	12	9.71	0.35	28.03	0.73	0.46	0.00	3.58	1.01	7.10
8	0.24	0.00	1.22	0.82	4	8.19	0.27	21.78	0.99	0.50	0.00	3.81	0.95	7.62
9	0.25	0.00	1.25	0.80	12	9.13	0.32	25.57	0.99	0.47	0.00	4.58	1.07	9.62
10	0.24	0.00	1.22	0.82	4	8.15	0.27	21.62	1.10	0.47	0.00	4.17	0.85	8.52
11	0.25	0.00	1.25	0.80	12	9.71	0.35	28.03	1.21	0.48	0.00	5.17	1.03	11.29
12	0.28	0.00	1.46	0.69	16	10.34	0.38	30.77	1.12	0.44	0.00	3.81	0.64	7.62
13	0.26	0.00	1.33	0.75	16	10.32	0.38	30.67	0.73	0.32	0.00	4.58	0.74	9.62
14	0.31	0.02	1.71	0.58	16	11.81	0.46	37.44	1.49	0.48	0.07	5.17	0.81	11.29
15	0.31	0.02	1.71	0.58	16	11.39	0.44	35.51	1.68	0.50	0.04	5.58	0.84	12.56
16	0.33	0.07	1.93	0.52	16	13.46	0.56	45.44	1.88	0.52	0.03	5.91	0.85	13.58
17	0.26	0.00	1.32	0.76	16	10.00	0.36	29.26	1.13	0.38	0.00	6.02	0.82	13.95
18	0.24	0.00	1.22	0.82	4	7.98	0.26	20.95	1.20	0.39	0.00	5.09	0.61	11.05
19	0.33	0.08	1.93	0.52	16	10.61	0.39	31.97	1.47	0.43	0.00	4.81	0.54	10.24
20	0.26	0.00	1.35	0.74	12	9.86	0.35	28.65	0.92	0.31	0.00	5.25	0.58	11.52
21	0.25	0.00	1.30	0.77	12	8.88	0.30	24.55	0.99	0.32	0.00	5.83	0.64	13.34
22	0.26	0.00	1.35	0.74	12	9.86	0.35	28.65	1.07	0.33	0.00	6.25	0.67	14.70
23	0.34	0.06	1.35	0.74	16	12.46	0.50	40.54	2.20	0.50	0.11	7.32	0.80	18.48
24	0.34	0.07	1.97	0.51	16	10.21	0.37	30.18	1.23	0.35	0.00	6.39	0.63	15.19
25	0.35	0.11	2.10	0.48	16	13.17	0.54	44.01	1.49	0.39	0.02	7.17	0.72	17.92
26	0.24	0.00	1.22	0.82	4	7.78	0.25	20.20	1.25	0.35	0.00	5.64	0.49	12.74
27	0.33	0.05	1.88	0.53	16	12.91	0.53	42.71	1.42	0.37	0.01	7.17	0.66	17.92
28	0.29	0.00	1.55	0.64	12	9.55	0.34	27.35	1.00	0.29	0.00	5.75	0.47	13.09
29	0.28	0.00	1.48	0.67	12	9.49	0.33	27.09	1.04	0.29	0.00	5.81	0.46	13.26
30	0.32	0.03	1.84	0.54	12	9.52	0.34	27.22	0.99	0.28	0.00	5.75	0.44	13.09

31	0.26	0.01	1.36	0.74	8	7.61	0.24	19.57	1.23	0.32	0.00	5.91	0.44	13.58
32	0.27	0.01	1.42	0.70	8	8.61	0.29	23.46	1.10	0.30	0.02	6.49	0.49	15.53
33	0.35	0.08	2.10	0.48	14	12.32	0.49	39.88	1.21	0.31	0.02	7.75	0.61	20.10
34	0.27	0.01	1.37	0.73	12	10.29	0.38	30.51	0.88	0.25	0.00	6.81	0.49	16.63
35	0.39	0.17	2.42	0.41	14	14.58	0.63	51.14	1.29	0.32	0.01	7.70	0.57	19.89
36	0.33	0.03	1.76	0.57	14	11.34	0.44	35.27	0.95	0.32	0.00	7.34	0.52	18.55
37	0.37	0.08	2.19	0.46	16	12.98	0.53	43.06	1.98	0.41	0.07	9.58	0.74	27.48
38	0.31	0.00	1.69	0.59	12	9.01	0.31	25.08	1.31	0.32	0.00	7.13	0.47	17.78
39	0.29	0.01	1.59	0.63	12	9.91	0.36	28.86	1.31	0.31	0.00	6.91	0.44	16.98
40	0.25	0.00	1.24	0.81	8	8.32	0.28	22.30	0.94	0.24	0.00	6.29	0.37	14.83
41	0.31	0.06	1.71	0.58	12	10.13	0.37	29.83	1.37	0.32	0.02	8.21	0.53	21.87
42	0.31	0.06	1.74	0.57	14	12.08	0.48	38.71	0.00	0.00	0.00	5.39	0.28	11.96
43	0.29	0.04	1.59	0.63	14	11.70	0.46	36.94	0.00	0.05	0.00	6.39	0.35	15.19
44	0.33	0.07	1.87	0.53	14	11.58	0.45	36.40	1.28	0.30	0.09	7.75	0.46	20.10
45	0.30	0.01	1.64	0.61	12	9.13	0.32	25.57	1.14	0.27	0.04	7.32	0.41	18.48
46	0.33	0.03	1.88	0.53	14	12.49	0.50	40.70	1.20	0.28	0.02	8.17	0.47	21.70
47	0.34	0.04	1.97	0.51	14	12.49	0.50	40.70	1.21	0.28	0.02	8.17	0.46	21.70
48	0.31	0.09	1.76	0.57	8	9.00	0.31	25.03	1.57	0.33	0.06	7.49	0.40	19.11
49	0.35	0.11	2.10	0.48	14	12.86	0.52	42.48	1.71	0.35	0.04	9.17	0.53	25.74
50	0.28	0.00	1.51	0.66	8	8.95	0.31	24.84	1.22	0.28	0.00	7.39	0.37	18.74
51	0.27	0.00	1.39	0.72	8	8.91	0.30	24.65	1.20	0.27	0.00	7.58	0.38	19.46
52	0.30	0.08	1.64	0.61	14	11.75	0.46	37.20	1.23	0.27	0.00	7.58	0.37	19.46
53	0.24	0.00	1.20	0.83	4	7.81	0.25	20.30	0.95	0.22	0.00	6.46	0.29	15.42
54	0.24	0.00	1.19	0.84	8	8.75	0.30	24.03	0.98	4.30	0.00	7.58	0.36	19.46
55	0.24	0.00	1.19	0.84	8	9.64	0.34	27.73	1.00	0.23	0.00	7.49	0.35	19.11
56	0.23	0.00	1.16	0.87	8	9.23	0.32	25.98	0.97	0.22	0.00	7.70	0.36	19.89
57	0.30	0.02	1.61	0.62	14	11.17	0.43	34.49	1.23	0.27	0.01	7.64	0.35	19.68
58	0.24	0.00	1.17	0.85	8	8.56	0.29	23.25	0.00	0.00	0.00	5.86	0.23	13.42
59	0.27	0.05	1.42	0.70	8	9.39	0.33	26.67	1.29	0.27	0.03	7.81	0.34	20.30
60	0.27	0.05	1.38	0.72	10	8.83	0.30	24.35	0.96	0.22	0.00	7.44	0.32	18.93
61	0.29	0.05	1.60	0.62	12	11.63	0.45	36.61	0.77	0.18	0.00	6.91	0.28	16.98
62	0.24	0.00	1.23	0.82	10	10.09	0.37	29.64	0.79	0.18	0.00	7.49	0.31	19.11
63	0.31	0.08	1.71	0.58	14	13.55	0.57	45.89	1.24	0.26	0.01	9.39	0.42	26.67
64	0.29	0.01	1.44	0.70	10	9.00	0.31	25.03	0.66	0.19	0.00	7.54	0.30	19.29
65	0.35	0.16	2.05	0.49	14	13.13	0.54	43.81	1.55	0.30	0.08	8.70	0.37	23.81
66	0.28	0.02	1.51	0.66	12	9.70	0.35	27.97	1.28	0.26	0.02	7.46	0.29	18.99
67	0.28	0.00	1.46	0.69	12	9.75	0.35	28.21	1.22	0.25	0.00	8.00	0.31	21.04
68	0.27	0.01	1.39	0.72	12	9.87	0.35	28.70	1.23	0.26	0.01	8.91	0.36	24.65
69	0.32	0.04	1.75	0.57	14	12.56	0.51	41.04	1.43	0.29	0.02	9.39	0.39	26.67
70	0.27	0.00	1.45	0.69	12	9.63	0.34	27.67	1.30	0.26	0.00	8.98	0.36	24.94
71	0.28	0.00	1.35	0.74	8	9.17	0.32	25.74	1.21	0.25	0.00	7.04	0.25	17.47
72	0.32	0.02	1.35	0.74	14	9.13	0.32	25.57	1.24	0.31	0.02	8.02	0.29	21.13
73	0.31	0.08	1.75	0.57	14	12.64	0.51	41.43	1.58	0.30	0.04	10.17	0.41	30.01
74	0.30	0.00	1.47	0.68	14	11.13	0.42	34.30	1.39	0.29	0.00	9.63	0.37	27.67
75	0.27	0.00	1.40	0.72	12	11.04	0.42	33.91	1.25	0.25	0.00	8.13	0.29	21.54
76	0.30	0.05	1.61	0.62	12	11.17	0.43	34.49	1.51	0.29	0.01	9.58	0.36	27.48
77	0.25	0.00	1.27	0.79	12	10.00	0.36	29.26	1.22	4.05	0.00	8.91	0.32	24.65
78	0.24	0.00	1.19	0.84	4	8.23	0.27	21.93	1.16	0.23	0.00	7.23	0.23	18.14
79	0.25	0.00	1.27	0.79	12	10.17	0.37	30.01	1.25	0.25	0.00	8.98	0.32	24.94
80	0.23	0.00	1.14	0.88	4	8.25	0.27	22.01	1.14	0.23	0.00	7.25	0.23	18.21

Switching medium node
Creative insight
Highest vs. lowest degree of integration or t-code measures
Imposed constraint (new request)

7.5 Designer 3 – Case Study 2 Structured Brief for *Cheese Factory*

7.5.1 Description of Concept Initiation

This design experiment started with an analytical study of the design programme, functional requirements, and site-layout in the design brief. This phase of *concept initiation* was built on the provided instructions and proposed scenario. The architect read through the programme's scenario, wrote down some keywords, and traced over the given site plan (overlaid a tracing sheet). This approach continued during this thinking process and all through. It signified the association with the information provided, which was used as a base from which the architect could then depart in his design.[85]

A zoning diagram was developed based on replication of the design brief rather than reflecting on the 'functional programme'. It was designed on the site-layout at sketching episode SK(1-1). This sketch was deployed as the 'primary proposal' to initiate the architectural concept of the master plans. This basic zoning diagram was transformed through the following phase and presented another sketching episode SK(1-2) – detailed 'zoning diagram' – which elaborated the relations between a variety of functional spaces.

Observing a *creative leap* emerging, this 'zoning diagram' SK(1-2) was deployed to design the 3-D perspective at 'one-go' sketching before designing the master plans. Episodes SK(1-3 *preliminary*) and SK(2-1 *detailed*) were designed simultaneously to transcribe the functional programme of episode SK(1-2), showing advanced sketching skills and imagination. The functional requirement was conveyed in simple 3-D forms of spatial configuration. Thus, the initiation phase reflected 'practicality' and 'simplicity'. It adopted a *top-down* design approach with the aim of achieving the predefined set of goals.

The development of a master plan went through a series of *transformational* sketching episodes. Information was retrieved *from time to time* by visiting the design brief during the intermediate operational phase ending with sketch SK(2-2). During this development, an imposition of external constraint to include an exhibition hall within the parti occurred in the design process. This caused the occurrence of a sudden mental insight to solve the problem. The architect flipped the master plan over, mirrored the design configuration of spaces and traced over the back side presenting sketching episode SK(3-1).[86] This action led to solving the problem and overcoming the disruption of the unpredicted event.

The interim goal at this stage was to change the positions of each functional space and to consider the fixed entrance and exits and vehicle circulation routes in the site-layout. Another major change to record for the impact of imposed constraint on the prevalent concept was the exclusion of the cylindrical-shaped entrance from the entire configuration. Although it had been a dominant element in the preceding 3-D model, it was replaced with a rectangular shape.

Following this action, the process was directed to designing the master plan in detail, providing dimensions, areas and percentages of functional spaces to achieve the requested programme, i.e. inlet and outlet, loading docks, refrigerator and storage, staircases and circulation elements. The pertinent actions at this sketching episode reflected the hierarchical *top-down* approach to achieve this predefined idea. The decision to attach the control room with the manufacturing hall incorporated the functional request for HVAC space – included in the functional programme – and the outlet's loading docks were relocated accordingly. Supplementary utilities were included: the water-chiller and air-conditioner. The final presentation of the master plan was designed and refined in two sketching episodes mirroring some spaces to explore every possible proposal and decide the best functional configuration.

The exhibition hall was included in the first floor, a mezzanine overlooking the production hall. The architectural treatment of a 'clearstory' provided indirect lighting panels for the triple height space.[87] In consequence, this design solution caused modification to the 3-D perspective that was developed through two sequential sketching episodes: SK(4-1) and SK(4-2). This was followed by outlining the

[85] See Appendix 7.3 to review the *segmentation*, *transcription* and *coding* processes for this experiment.

[86] Flipping the master or the tracing sheet is something architects often do to explore solutions through different (mirrored) arrangements for functional zoning.

[87] In architecture clearstory (clerestory or over-storey) refers to any high windows above eye level. The purpose is to bring outside light or fresh air into the inner space.

'cross-section' sketch SK(4-3), cutting through the main space, mounted mezzanine, and clearstory. Although this 'section' appeared at the end of process (the last product), the conceptual form was preconceived in the architect's mind throughout the process. It confirmed the concept of 3-D perspective that was designed in the initiation phase, episode SK(1-3), while the design configuration was transformed after the imposition of external constraint by excluding the cylindrical mass. Figures 7.19 and 7.20 illustrate the *interim products* and *transformation* throughout this experiment.

7.5.2 Qualitative Description: Identification of Critical Moves and Creative Insights

Our approach to identifying the *creative leaps* and *sudden mental insights* ranges from describing the concept initiation, development, and transformation phases until producing the final artefact of design concept. We aim to reveal the structure of reasoning and capture the events of drastic paradigm shifts. Two primary forms of reasoning are investigated in this context: *incremental* insights *reframe* the design solution and *preserve* the initial concept; while *sudden* insights *restructure* the whole design problem and *redefine* the goals aiming to explore the design space for possible solutions for any imposed or unforeseen requirements.

Design action 4 emerged while reading the design brief. The architect spent a moment thinking and considered that there was a missing function in the programme: the need for a 'logistics zone' in the factory. In the retrospective comments (after the completion of experiment), the architect justified this decision stating that this logistics zone would play an intermediate functional role between the packaging line and temporary storage before loading at the outlet docks. This node was the first iteration on sketch while placing a tracing sheet over the brief's site-layout – starting with mapping the primary functional requirements and bubble diagram of relations.

Design action 8 reflected a creative leap at sketching episode SK(1-3); sketching the 3-D perspective for the project based on an abstract outline for the zoning diagram. This event framed the solution until the end of the design process. It was recalled several times during development. It was transformed after the imposition of the external constraint – replacing the cylinder with rectangular form.

The decision to create a 'universal space' for manufacturing and clearstory for lighting took place at this action, which was later recalled to design the sketching episode SK(4-3) at action 75. This concept persisted through the stages of development until the end. Although, the design problem was decomposed into micro sets, this *top-down* approach continued. The problem-solving process dealt with the conceptual configuration of the whole composition and ended with miniature phases to elaborate on the functional relations and design details. Once an unpredicted constraint occurred, the perseverance and re-framing of the initial concept resumed to continue the *top-down* hierarchical relation between the contents of design and structure of reasoning.

Action 26 is a sudden insight with the aim of solving the imposed problem by restructuring the whole design configuration in order to explore different possibilities for solution. Episodes 36 and 55 are artefacts of *incremental* reasoning and articulation with the interim artefacts. Action 36 describes an operational phase taking place where the architect worked on specifying the functional programme in detail. Each space requirement was solved within the whole. This sketching episode presented a detailed master plan drawn to scale at action 54 of sketch SK(3-2). Action 55 however is a *replication* where the architect traced over the base plan and made a slight transformation by mirroring around the entrance.

7.5.3 Impact of Imposing External Constraint

- **On Design Reasoning**

A state of incremental reasoning prevailed in the design process until the unforeseen imposition of a functional requirement. At this initial stage, the process took a *top-down* approach to achieve the predefined set of goals of the functional programme. The reasoning process was transformed after the external constraint to become non-incremental. The design problem was restructured while flipping the whole configuration of master plan around with an attempt to redefine the set of relations between the functional spaces.

- **On Transformation of Ideas**

A state of *perseverance on the initial concept* prevailed through the design process until the imposition of the external request. A disruption phase was experienced for a few actions with attempts to solve the problem. Lateral transformation was pursued to change the configuration and rearrange the relations between the functional spaces, e.g. the cylindrical entrance was omitted and the master plan was redesigned. However, the concept was developed and modified in relation to the previous solution. The final outcomes preserved the developed (hybrid) solution. The 3-D perspective, façades and cross-section were designed (see Figures 7.19 and 7.20). Figures 7.21 and 7.22 show the annotation of sketching episodes, creative insights and concept transformations via back/forelinking and the linkography protocol of this design experiment.

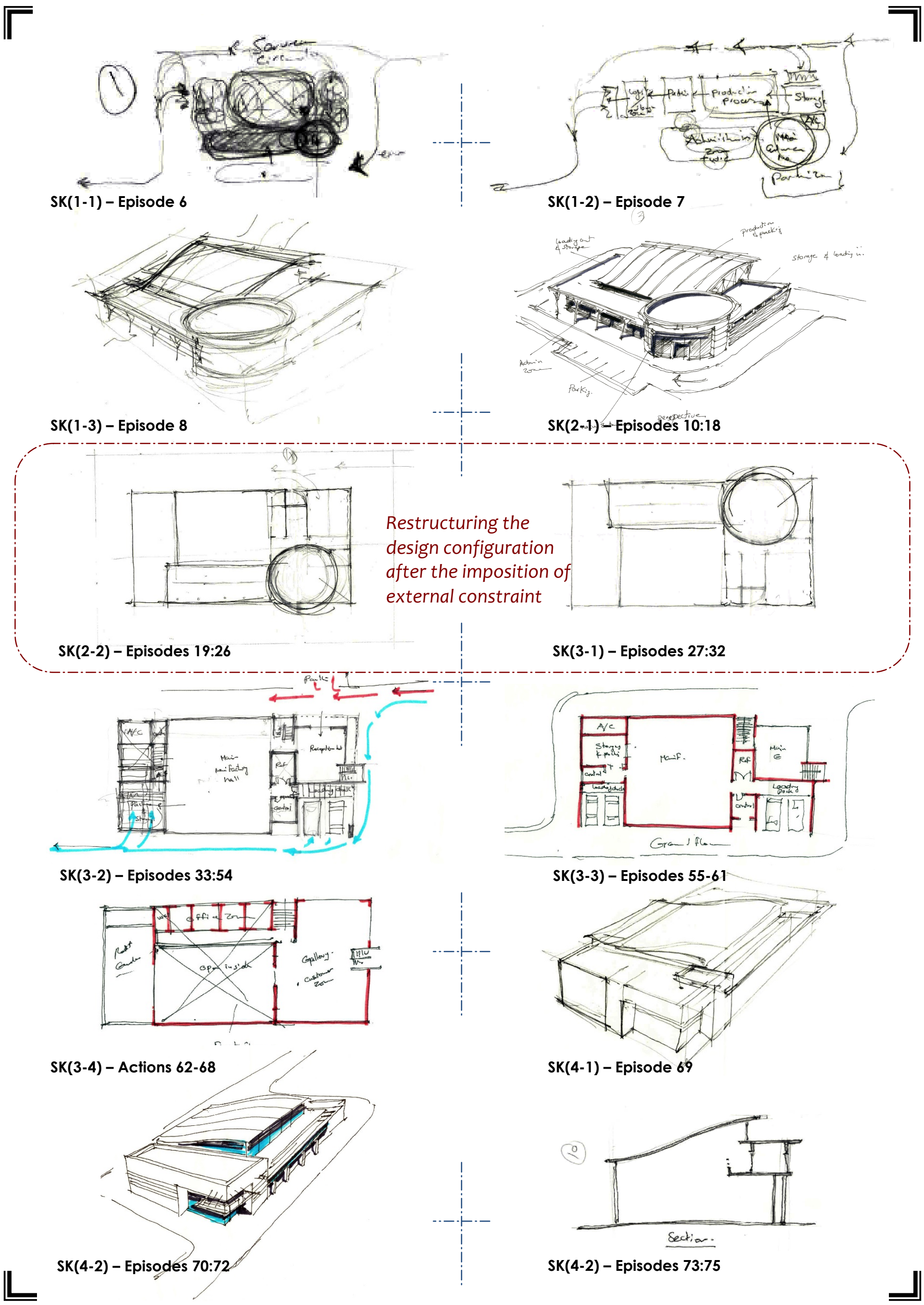


Figure 7.19 Interim artefacts signify multiple proposals (Case Study 2, Designer 3)

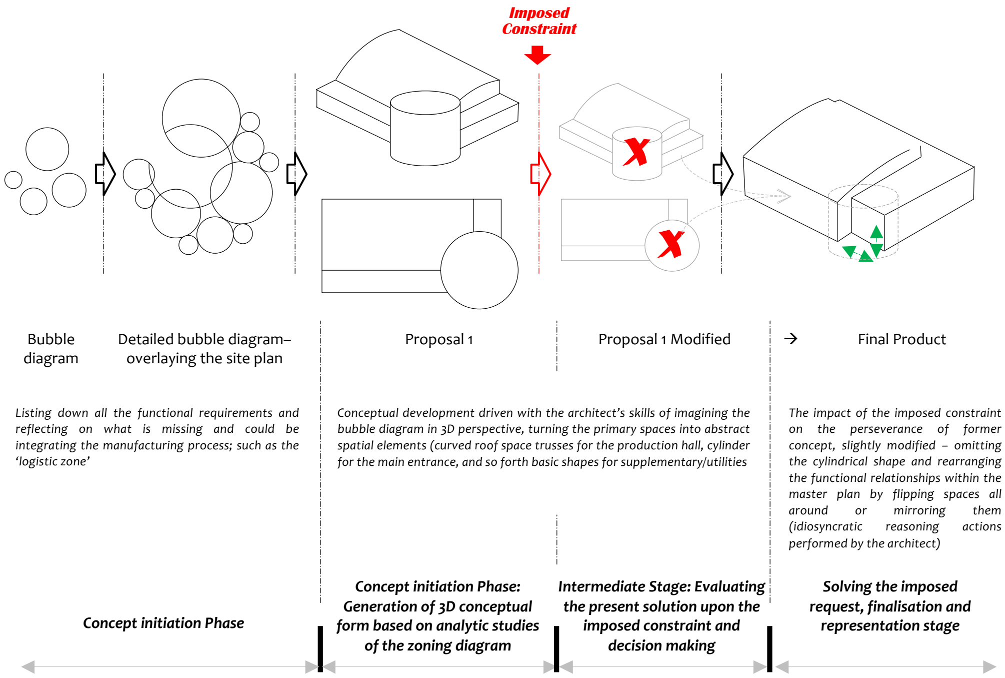


Figure 7.20 Transformation of concept through the spatial configuration of forms (Case Study 2, Designer 3)

7.5.4 Correlation with Quantitative Measurements

This section investigates the context beyond the emergence of creative insights in highly specified and constrained design problems. Through linkography, network analysis and sets of quantitative measurements, the correspondence between sketching episodes and structure of reasoning can be inferred using a joint model that correlates qualitative and quantitative judgements of the design actions and products. In this correlation, the relationships between the design episodes are examined in the linkograph and corrected if any dependency relation is missing or mistakenly added. This looped way of coding the relations and periodic phases of correction assures reliability and validation of the model and provides objective descriptions of the design process to deduce the emergence of creative actions, formation of novel concepts and the relation between contents of design and structure of reasoning.

Two creative events are identified through the model as taking place in this design experiment: episodes 8 and 26. In the following description, the structure of network for each action is quantified in comparison to the whole linkograph via different sets of measures (integration, connectivity and t-codes sets) to capture the multilevel complexity and its hierarchical structure of reasoning. Further, actions that deliver significant values are investigated to shed light on the context beyond the highest and lowest episodes of design. Figures 7.23, 7.24, 7.25 and 7.26 illustrate the connectivity for the critical nodes; measurements for concatenation; backlink relations; and network analysis respectively. Table 7.4 presents a variety of measurements for this design case. Thus, the following actions are investigated:

- Action 33 delivers the maximum integration value.
- Actions 71 and 72 deliver the minimum integration value.
- Action 55 delivers the maximum t-code measures.
- Action 40 delivers the minimum t-code measures.
- Action 33 delivers the maximum connectivity.

Episode 8 is a creative leap: designing a 3-D conceptual idea based on the architect's imagination for the form and spatial configuration rather than constructing it using the more traditional method of tracing the master plan.[88] This event appeared after analysing the design brief through bubble diagram. This concept was recalled three times until the ending phase of final product: sketching episodes SK(2-1), SK(4-1) and SK(4-3) of actions 10, 69 and 75 respectively. This action is connected with 8 links in total (3 *backlinks* and 5 *forelinks*). It delivers median integration value 1.49 that reflects median structure of relations (not shallow, not deep). Concatenated strings of information deliver high values compared to the rest of the vertices: t-complexity 11.91 (taugs) and t-entropy 0.5 (bits/char).

Episode 26 is a creative sudden insight, making a paradigm shift to a new frame of reference by restructuring the design situation while designing the master plan, solving the design configuration and reintroducing relations between the functional spaces. Architects have different idiosyncrasies to facilitate design performance if a fixation point is faced, such as flipping the drawing around and retracing over the event to explore different boundaries for the solution. This design action was recalled twice, structuring the process at sketches SK(3-1) and SK(3-2) of episodes 27 and 36 respectively. It is connected with four links (2 *backlinks* and 2 *forelinks*). The local network of relations created at this node delivers median integration value of 1.58 (not shallow, not deep). Concatenated strings of information deliver low values: t-complexity 9.32 (taugs) and t-entropy 0.35 (bits/char).

Episode 33 delivers the maximum integration value of 2.72. This action was a starting point for a sketching episode SK(3-2). In this sketch, the master plan for the proposed factory was developed and detailed, and the functional programme and spatial relationships were achieved. It continued for a sequence of design steps that reflect an accumulative process of incremental reasoning with the interim product. The following design actions were highly structured and linked with action 33, reflecting a hierarchical relation between the contents and structure of reasoning at this stage. Thus, this action is highly connected and delivers the maximum *connectivity* in the whole linkograph with a total of 26 links (3 *backlinks* and 23 *forelinks*). However, the integration value is the lowest in the whole network. Concatenated strings of information deliver high values: t-complexity 12.91 (taugs) and t-entropy 0.56 (bits/char).

Action 40 delivers the lowest t-code measures in the whole linkograph. It is a secondary action to add 'dotted' lines for the first floor profile on sketch SK(3-2) (comment: 'These are hidden lines for the upper floor'). This action is linked with one *backlink* only. It delivered median integration value 1.58 that reflects median structure of relations (not shallow, not deep). Concatenated strings of information deliver the minimum values of all in the linkograph: t-complexity 7.17 (taugs) and t-entropy 0.24 (bits/char).

Episode 55 delivers the maximum t-code measures in the linkograph reflecting diversity in the arrangement of sets of codes of information. This action is a starting point to design sketching episode SK(3-3). It is a replication of the preceding sketch SK(3-2). The master plan was enhanced and refined with slight changes, flipping the location between the 'storage' space and 'outlet dock'. This action is thus connected with 10 links in total (1 *backlink* and 9 *forelinks*). It structured the following actions on the master plan to those modifications. This vertex delivers high integration value of 2.07 for a shallow system. Concatenated strings of information deliver high values: t-complexity 13.58 (taugs) and t-entropy 0.61 (bits/char).

Episodes 71 and 72 deliver the minimum integration value 0.88 in the whole linkograph for deep structure of relations. Both design actions appeared in sketching episode SK(4-2). Episode 71 is about 'overlaying shadows' representing the final 3-D perspective and episode 72 is about 'adding details' for the 'glazing' façades. Both actions are weakly connected with only one *backlink* to the starting point of this sketch SK(4-2), at node 70. Concatenated strings of information deliver low values; t-code measures for episode 71 are: t-complexity 8.13 (taugs) and t-entropy 0.28 (bits/char), and the results for episode 72 are: t-complexity 8.17 (taugs) and t-entropy 0.29 (bits/char).

[88] Two ways to sketch/design 3-D perspective can be distinguished here: (1) The traditional way is to design the façade first then the 3-D perspective, which is to trace the projection (construction) lines from the master plan then construct the façade (2-D Master plan > 2-D façade and/or 2-D section > 3-D perspective or isometric). (2) The generative way is where the architect designs and sketches the 3-D perspectives from his/her own imagination. In the case of sketching episode 8, the architect avoided the more usual traditional way and used his own imagination.

7.5.5 Results and Discussion

Addressing the transformation of concepts through the sketching episodes and through pairwise comparisons, *lateral* and *vertical* types of transformation are examined in this design process aiming to reveal the relation between the contents and reasoning structure.

For example, the zoning diagrams at sketches SK(1-1) and SK(1-2) reflect vertical transformation reframing the solution. The relations between functional spaces were identified at the preliminary sketch SK(1-1) and were detailed at the following episode of SK(1-2) preserving the concept. This is a hierarchical approach to achieve the goals of design through a sequence of incremental events.

Sketch SK(1-3) is a creative leap. The 3-D configuration is designed and transfers the zoning diagram into spatial configuration. It is considered a lateral transformation of the concept since new conceptual elements were brought to the composition to introduce the architectural form. However, the process still adopts a hierarchal approach to continue what was defined at the earlier stage of concept initiation. The following sketch SK(2-1) is a 3-D perspective that replicated the preceding concept of sketch SK(1-3) with details. The spatial configuration remained at this stage without modification and thus the transformation is considered vertical.

The imposition of the constraint restructured the design situation. At sketch SK(2-2), the reason behind the decision to exclude the cylindrical entrance was to enlarge the zone's area and include the requested exhibition hall within. Flipping then mirroring the functional configuration all around (at sketches SK(2-2) and SK(3-1) of x-ray conceptual plans) reflected the lateral transformation process between the contents and structure of reasoning. At this stage, the transformation led to significant modification of the design scenario and concept. Sketch SK(3-2) is proposed to reflect the modified concept on the master plan that provided the final solution for the imposed problem of external constraint.

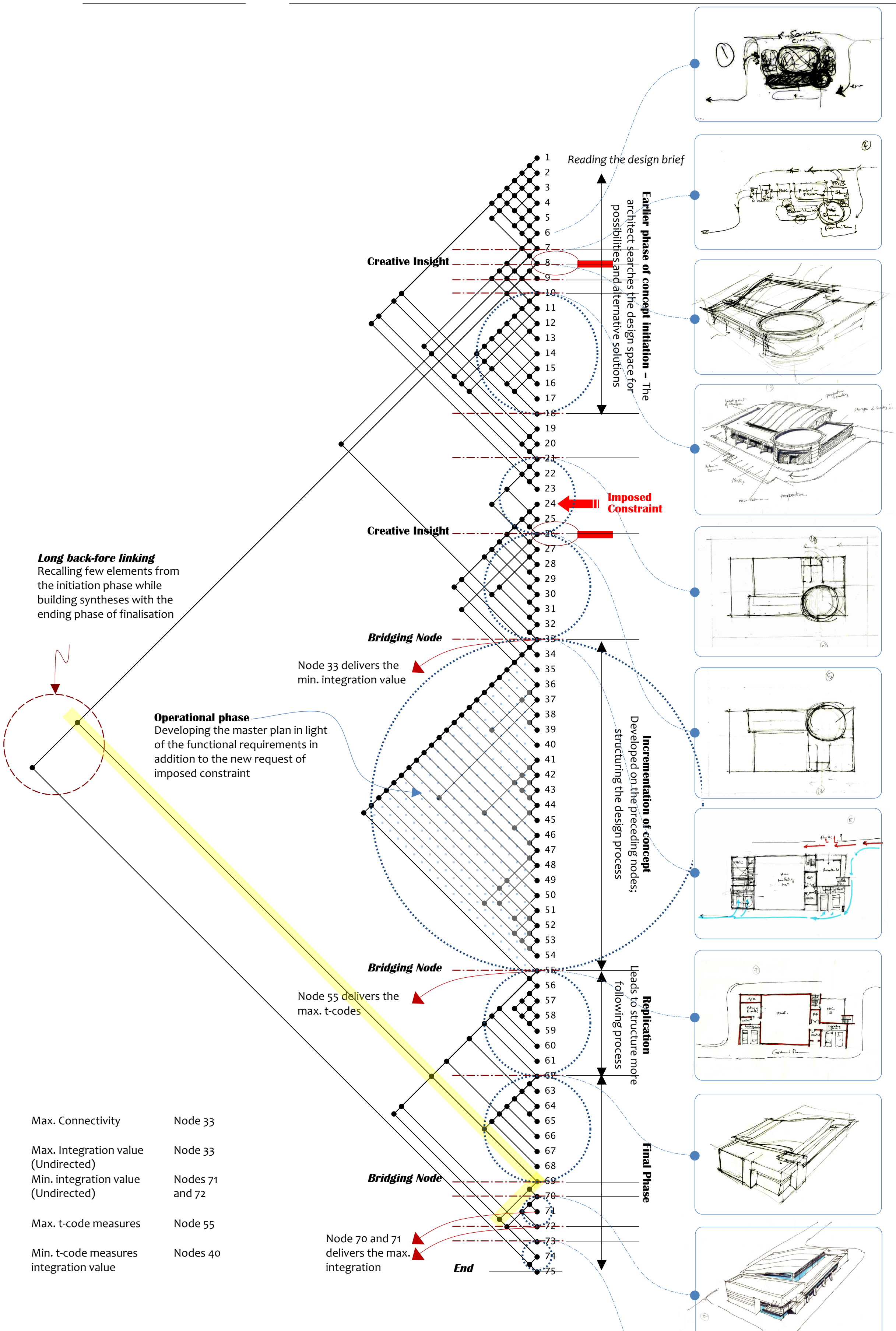
This was followed by another decision to distribute the functional spaces between two floors. Sketching episodes SK(3-2), SK(3-3) and SK(3-4) are developments for the ground and first floor plans. The exhibition hall was located on the first floor overlooking the manufacturing hall. The transformation of ideas between those three sketches reframed the solution and solved the problem in detail.

The 3-D perspective is amended at sketch SK(4-1) to present the final solution. This outcome assured the perseverance of the prime concept of sketch SK(2-1) and the hierarchical relation between the content and reasoning. This concept was redrawn and refined at sketching episode SK(4-2). The final product of cross-section at sketch SK(4-3) reframed the concept and outlined the profile of universal space and clearstory of the factory with mounted mezzanine overlooking the hall. This action took into account the concept that was already initiated at the beginning and transformed throughout the process.

This design process included two *restructuring* events where the architect reintroduced the design configuration in a new form between the functional spaces. Restructuring the problem occurred at sketches SK(1-3) and SK(3-1) for actions 8 and 26 respectively.

Incremental reasoning prevails through this experiment until the imposition of the external constraint. The vast majority of events reframed the initial concept at sketches SK(2-1), SK(3-2), SK(3-3), SK(3-4), SK(4-2) and SK(4-3). However, different proposals were evaluated at the intermediate phase, which are pertinent to the functional programme, the configuration between the production line and supplementary equipment (e.g. refrigerator, steriliser, packing, loading docks, storage, control room and HVAC).

Many decisions were taken during this operational phase to explore a variety of proposals responding to the functional requirements. Those actions also reflected perseverance in reframing the concept leaving a margin for minor modifications after the imposition of external condition.



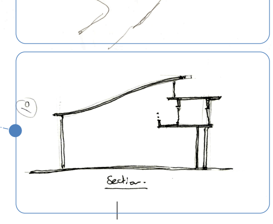


Figure 7.21 Annotation of creative insights, sketching contents, concept transformations via back/fore linking and sketching exchanges (Case Study 2, Designer 3)

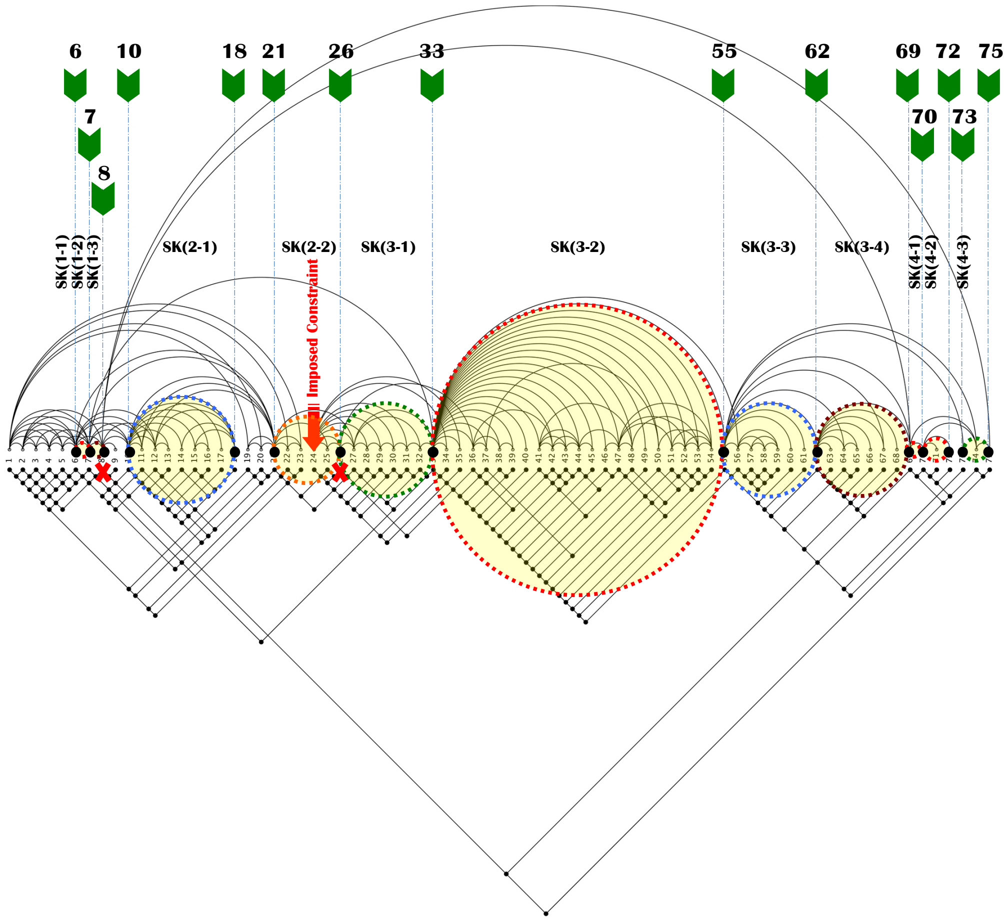


Figure 7.22 Linkography protocol of the design process (Case Study 2, Designer 3)

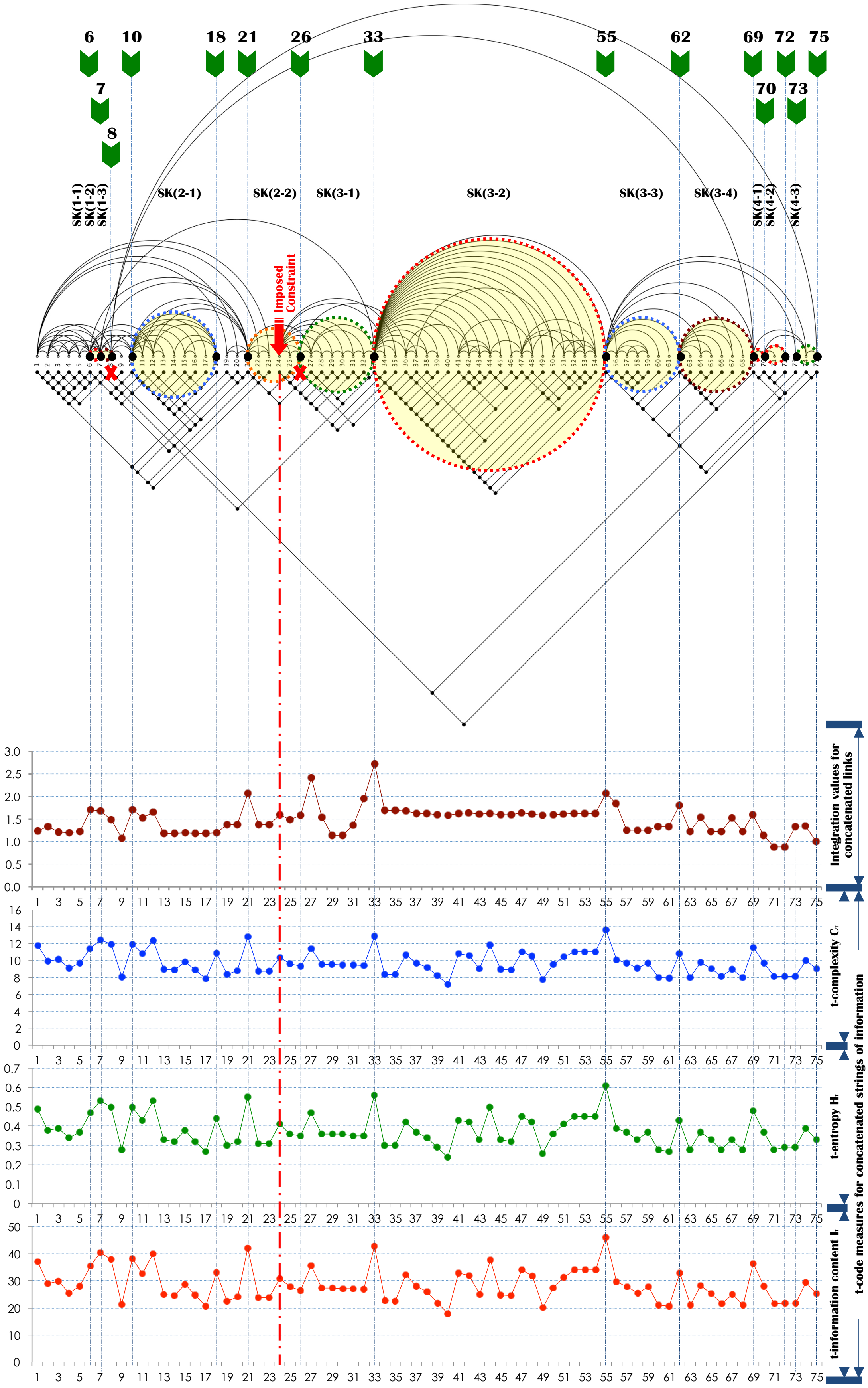


Figure 7.23 Quantitative measures for *concatenated* relations (Case Study 2, Designer 3)

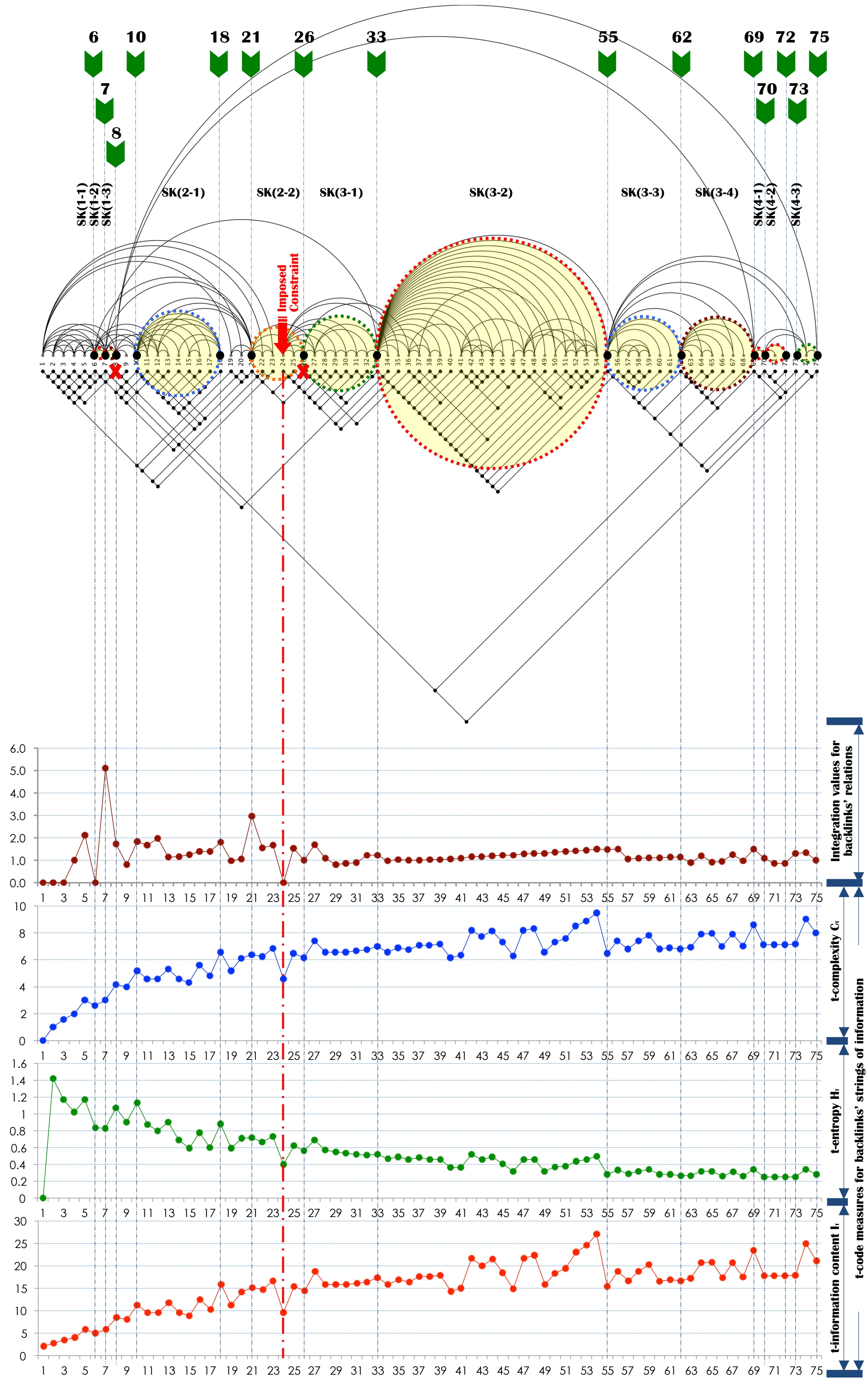


Figure 7.24 Quantitative measures for *backlink-directed* relations (Case Study 2, Designer 3)

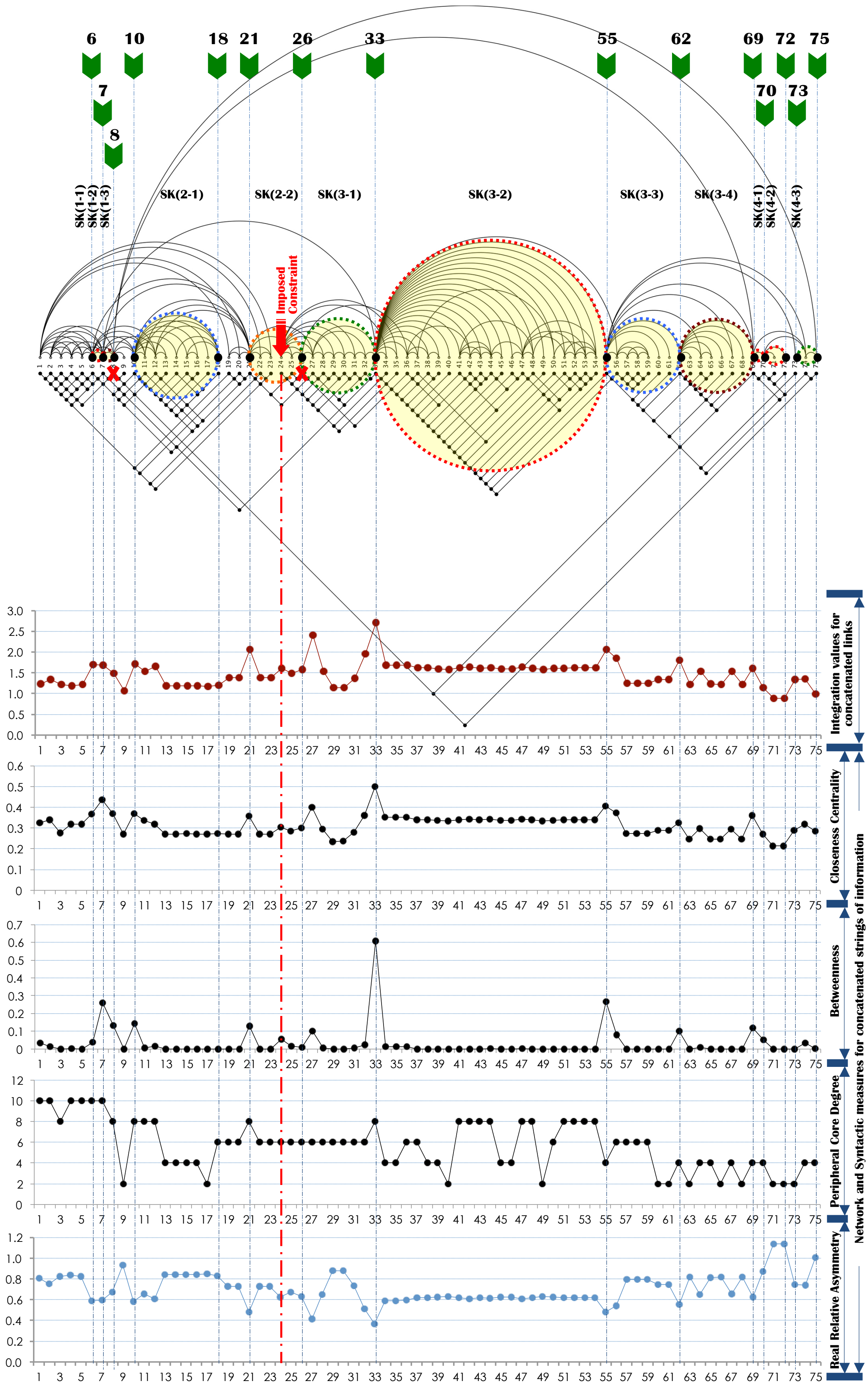


Figure 7.25 Network analysis for *concatenated* relations (Case Study 2, Designer 3)

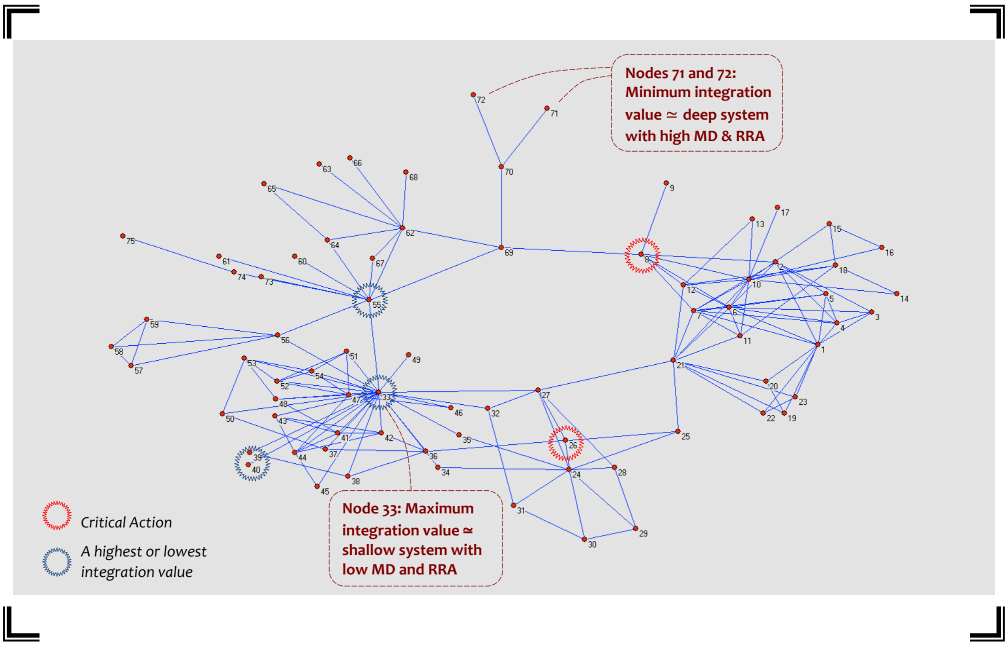


Figure 7.26 Distribution of the strength of integration of nodes in the linkograph (Case Study 2, Designer 3)

Table 7.4 All the quantitative measurements for the linkograph protocol (Case Study 2, Designer 3)

#	Undirected Measurements								Directed Measurements					
	Closeness Centrality	Betweenness Centrality	Global Integration	Real Relative Asymmetry (RRA)	Degree Peripheral Core	T-complexity Concatenated strings C_T	T-entropy Concatenated strings H_T	T-info Concatenated strings I_T	Integration – Back Relations	Closeness Centrality – Back Relations	Betweenness Centrality – Back Relations	T-complex – Back strings C_T	T-entropy – Back strings H_T	T-information – Back strings I_T
1	0.33	0.03	1.24	0.81	10.00	11.73	0.49	37.07	0.00	0.00	0.00	0.00	0.00	2.09
2	0.34	0.01	1.33	0.75	10.00	9.89	0.38	28.81	0.00	1.00	0.00	1.00	1.42	2.84
3	0.28	0.00	1.21	0.83	8.00	10.13	0.39	29.83	0.00	1.00	0.00	1.58	1.17	3.50
4	0.32	0.00	1.19	0.84	10.00	9.11	0.34	25.48	1.00	1.00	0.00	2.00	1.02	4.08
5	0.32	0.00	1.22	0.82	10.00	9.69	0.37	27.94	2.11	0.80	0.00	3.00	1.17	5.84
6	0.37	0.04	1.70	0.59	10.00	11.37	0.47	35.39	0.00	1.00	0.03	2.58	0.84	5.04
7	0.44	0.26	1.68	0.60	10.00	12.43	0.53	40.38	5.09	0.86	0.00	3.00	0.83	5.84
8	0.37	0.13	1.49	0.67	8.00	11.91	0.50	37.91	1.72	0.64	0.00	4.17	1.07	8.52
9	0.27	0.00	1.07	0.93	2.00	8.07	0.28	21.29	0.81	0.42	0.00	4.00	0.90	8.09
10	0.37	0.14	1.71	0.58	8.00	11.95	0.50	38.12	1.83	0.60	0.00	5.17	1.13	11.29
11	0.34	0.01	1.53	0.65	8.00	10.78	0.43	32.72	1.66	0.56	0.00	4.58	0.87	9.62
12	0.32	0.02	1.65	0.61	8.00	12.37	0.53	40.10	1.96	0.58	0.00	4.58	0.80	9.62
13	0.27	0.00	1.18	0.84	4.00	8.98	0.33	24.94	1.14	0.43	0.00	5.32	0.90	11.75
14	0.27	0.00	1.18	0.84	4.00	8.86	0.32	24.45	1.16	0.42	0.42	4.58	0.69	9.62
15	0.27	0.00	1.19	0.84	4.00	9.86	0.38	28.65	1.24	0.42	0.00	4.32	0.59	8.92
16	0.27	0.00	1.18	0.84	4.00	8.91	0.32	24.65	1.39	0.44	0.00	5.58	0.78	12.56
17	0.27	0.00	1.18	0.85	2.00	7.88	0.27	20.59	1.39	0.43	0.00	4.81	0.60	10.24
18	0.28	0.00	1.20	0.83	6.00	10.86	0.44	33.07	1.79	0.49	0.02	6.58	0.88	15.85
19	0.27	0.00	1.38	0.73	6.00	8.37	0.30	22.47	0.98	0.34	0.00	5.17	0.59	11.29
20	0.27	0.00	1.38	0.73	6.00	8.78	0.32	24.14	1.07	0.35	0.00	6.09	0.71	14.17
21	0.36	0.13	2.07	0.48	8.00	12.78	0.55	42.12	2.98	0.59	0.12	6.39	0.72	15.19
22	0.27	0.00	1.38	0.73	6.00	8.73	0.31	23.92	1.55	0.43	0.00	6.25	0.67	14.70
23	0.27	0.00	1.38	0.73	6.00	8.73	0.31	23.92	1.67	0.44	0.00	6.83	0.73	16.72
24	0.30	0.06	1.60	0.62	6.00	10.36	0.41	30.83	0.00	0.00	0.00	4.58	0.40	9.62
25	0.29	0.02	1.48	0.67	6.00	9.64	0.36	27.73	1.53	0.40	0.08	6.46	0.62	15.42
26	0.30	0.01	1.58	0.63	6.00	9.32	0.35	26.37	1.00	0.30	0.00	6.17	0.56	14.44
27	0.40	0.10	2.41	0.41	6.00	11.43	0.47	35.67	1.69	0.41	0.07	7.39	0.69	18.74
28	0.30	0.01	1.54	0.65	6.00	9.55	0.36	27.35	1.08	0.31	0.00	6.58	0.57	15.85
29	0.24	0.00	1.14	0.88	6.00	9.52	0.36	27.22	0.82	0.25	0.00	6.58	0.55	15.85

30	0.24	0.00	1.14	0.88	6.00	9.49	0.36	27.09	0.85	0.25	0.00	6.58	0.53	15.85
31	0.28	0.00	1.37	0.73	6.00	9.46	0.35	26.95	0.89	0.26	0.00	6.64	0.52	16.05
32	0.36	0.02	1.95	0.51	6.00	9.43	0.35	26.81	1.21	0.32	0.02	6.75	0.51	16.44
33	0.50	0.61	2.72	0.37	8.00	12.91	0.56	42.71	1.23	0.42	0.06	7.00	0.52	17.31
34	0.35	0.01	1.69	0.59	4.00	8.39	0.30	22.58	0.99	0.33	0.01	6.58	0.47	15.85
35	0.35	0.01	1.69	0.59	4.00	8.36	0.30	22.44	1.02	0.34	0.01	6.91	0.49	16.98
36	0.35	0.01	1.68	0.60	6.00	10.67	0.42	32.23	1.01	0.33	0.00	6.75	0.46	16.44
37	0.34	0.00	1.62	0.62	6.00	9.70	0.37	27.97	1.00	0.32	0.00	7.09	0.48	17.63
38	0.34	0.00	1.62	0.62	4.00	9.21	0.34	25.90	1.03	0.32	0.00	7.09	0.46	17.63
39	0.34	0.00	1.59	0.63	4.00	8.21	0.29	21.85	1.04	0.32	0.00	7.17	0.46	17.92
40	0.33	0.00	1.58	0.63	2.00	7.17	0.24	17.92	1.06	0.32	0.00	6.13	0.36	14.31
41	0.34	0.00	1.62	0.62	8.00	10.81	0.43	32.84	1.09	0.32	0.00	6.32	0.36	14.95
42	0.34	0.00	1.64	0.61	8.00	10.58	0.42	31.84	1.16	0.34	0.00	8.17	0.52	21.70
43	0.34	0.00	1.61	0.62	8.00	9.00	0.33	25.03	1.17	0.33	0.00	7.71	0.46	19.94
44	0.34	0.00	1.63	0.61	8.00	11.86	0.50	37.68	1.21	0.34	0.00	8.13	0.49	21.54
45	0.34	0.00	1.59	0.63	4.00	8.95	0.33	24.84	1.21	0.34	0.00	7.32	0.41	18.48
46	0.34	0.00	1.59	0.63	4.00	8.86	0.32	24.45	1.23	0.34	0.00	6.29	0.32	14.83
47	0.34	0.00	1.64	0.61	8.00	11.04	0.45	33.91	1.28	0.34	0.00	8.17	0.46	21.70
48	0.34	0.00	1.61	0.62	8.00	10.52	0.42	31.57	1.31	0.35	0.00	8.32	0.46	22.30
49	0.33	0.00	1.58	0.63	2.00	7.75	0.26	20.10	1.31	0.34	0.00	6.58	0.32	15.85
50	0.34	0.00	1.60	0.62	6.00	9.52	0.36	27.22	1.35	0.35	0.00	7.29	0.37	18.35
51	0.34	0.00	1.61	0.62	8.00	10.46	0.41	31.28	1.38	0.35	0.00	7.58	0.38	19.46
52	0.34	0.00	1.62	0.62	8.00	11.04	0.45	33.91	1.42	0.35	0.00	8.49	0.44	22.97
53	0.34	0.00	1.62	0.62	8.00	11.04	0.45	33.91	1.46	0.36	0.00	8.87	0.46	24.50
54	0.34	0.00	1.62	0.62	8.00	11.04	0.45	33.91	1.50	0.36	0.00	9.49	0.50	27.09
55	0.41	0.27	2.07	0.48	4.00	13.58	0.61	46.07	1.47	0.36	0.00	6.46	0.28	15.42
56	0.37	0.08	1.85	0.54	6.00	10.09	0.39	29.64	1.51	0.36	0.00	7.39	0.33	18.74
57	0.28	0.00	1.25	0.80	6.00	9.67	0.37	27.85	1.07	0.27	0.00	6.81	0.29	16.63
58	0.28	0.00	1.25	0.80	6.00	9.09	0.33	25.39	1.09	0.27	0.00	7.39	0.32	18.74
59	0.28	0.00	1.25	0.80	6.00	9.67	0.37	27.85	1.12	0.27	0.00	7.81	0.34	20.30
60	0.29	0.00	1.34	0.75	2.00	8.00	0.28	21.04	1.11	0.27	0.00	6.78	0.28	16.53
61	0.29	0.00	1.34	0.75	2.00	7.91	0.27	20.68	1.13	0.27	0.00	6.91	0.28	16.98
62	0.32	0.10	1.80	0.56	4.00	10.81	0.43	32.84	1.15	0.27	0.00	6.81	0.27	16.63
63	0.25	0.00	1.22	0.82	2.00	8.02	0.28	21.13	0.88	0.22	0.00	6.95	0.27	17.15
64	0.30	0.01	1.54	0.65	4.00	9.78	0.37	28.32	1.20	0.28	0.00	7.91	0.32	20.68
65	0.25	0.00	1.23	0.82	4.00	9.04	0.33	25.22	0.92	0.22	0.00	7.95	0.32	20.86
66	0.25	0.00	1.22	0.82	2.00	8.13	0.28	21.54	0.93	0.22	0.00	7.00	0.26	17.31
67	0.30	0.00	1.53	0.65	4.00	8.98	0.33	24.94	1.25	0.29	0.00	7.91	0.31	20.68
68	0.25	0.00	1.22	0.82	2.00	8.00	0.28	21.04	0.96	0.23	0.00	7.04	0.26	17.47
69	0.36	0.12	1.60	0.62	4.00	11.58	0.48	36.40	1.51	0.35	0.06	8.61	0.34	23.46
70	0.27	0.05	1.15	0.87	4.00	9.71	0.37	28.03	1.09	0.26	0.00	7.11	0.25	17.70
71	0.21	0.00	0.88	1.14	2.00	8.13	0.28	21.54	0.85	0.21	0.00	7.13	0.25	17.78
72	0.21	0.00	0.88	1.14	2.00	8.17	0.29	21.70	0.87	0.21	0.00	7.13	0.25	17.78
73	0.29	0.00	1.34	0.75	2.00	8.17	0.29	21.70	1.31	0.29	0.00	7.17	0.25	17.92
74	0.32	0.03	1.35	0.74	4.00	10.00	0.39	29.26	1.33	0.31	0.02	9.00	0.34	25.03
75	0.29	0.00	1.00	1.00	4.00	9.02	0.33	25.12	1.00	0.29	0.00	8.02	0.28	21.13

Switching medium node
Creative insight
Highest vs. lowest degree of integration or t-code measures
Imposed constraint (new request)

7.6 Results and Discussion

The validation of the proposed descriptive scheme is examined while investigating the *evolution of thoughts* and *formation of concepts* through the *collective reflection-in-action* with sketching artefacts in two different contexts: 'unstructured' versus 'structured' design reasoning processes. The developed method has provided a rigorous approach to describe the relation between the design contents and reasoning structure. Combining the qualitative and quantitative analyses in a joint framework has ensured the reliability of results looking at the emergent actions from both perspectives. Each action was detected through qualitative judgements of concept development (e.g. pairwise comparisons of sketching episodes) and valued through the linkography measurements (e.g. correlations between depth measures, network analysis and strings of information). The dependency relations between actions are examined through a cyclic detection of the qualitative description of artefacts (at first hand), then the quantitative evaluation.

Adjusting the scale of segmentation into meaningful (non-trivial) design episodes aimed to capture the structure of reasoning for the gradual transformations of mental imagery, which had been validated by testing and correcting different coding methods. Accordingly, we captured the structure of occurring events and demarcated the emergence of critical moves and creative actions in design reasoning and linkographs. Collected data is combined with the ethnographic observations and the architects' retrospective comments on concept development and emergent designs from one state to another. Two parameters for coding the dependency relations between design moves are derived after investigating a variety of design processes. The creative qualities for design cognitive actions range between two poles: (1) reframing the solution – preserving the flow, and (2) restructuring the problem – defying the flow. The taxonomy of categories of actions under each pole is defined. With an eye to Sternberg's propulsion theory (1999, 2003), these qualities for creative contribution are transcribed to linkography configuration, which has revealed those venues where procedural or contextual components are contributed in the design process. In Table 7.5, Sternberg's models are introduced with a brief description of the context behind each of the eight types of creative contribution. Figure 7.27 concludes the configurations of linkography for each quality of contribution.[89]

Investigating the context beyond the emergence of *sudden insights* revealed the role the creative actions may play in the reasoning process. In *incremental* reasoning insights emerge during direct reflection-in-action with the present situation and reframe the existing solution without any drastic changes. In *non-incremental* reasoning sudden insights occur during the unexpected discovery of synthesis (unpredicted combinations between old ideas and present situations) and restructure the design problem. The effect of sudden insights extends to 'reformulate the design brief', and/or 'rearrange the entire design configuration'. The creative quality of critical actions and creative insights is evaluated according to how the emergent concept has motivated the final design product in relation to the design quality, functional requirements and response to the user's needs.

7.6.1 Creative Quality for Emergent Actions and Configurations of Linkograph

Sternberg's propulsion theory (1999, 2003) stated that a creative contribution represents an attempt to propel a field from 'wherever it is' to 'wherever the creator believes the field should go', and moves a field from one point to another (Sternberg, 2003: 125). In this sense, creativity is considered a form of leadership and contribution in the design process. Sternberg categorises design actions as:

i) *Actions that 'accept' the prevalent current paradigm, reframing the solution, called 'paradigms-preserving' contribution.* Actions leave the field where it is, where actions are found replicating and/or redefining the design situation, known as *replication* and *redefinition* actions. It might also move the field forward in the direction that it is already going in. This is categorised as *forward incrimination* or *advanced forward incrimination* actions.
ii) *Actions that 'reject' the current paradigm, reflecting divergent thinking to restructure the design problem, called 'paradigms-rejecting' contribution.* Actions move the field in a new direction from an *existing* or *pre-existing* starting point, where actions are found redirecting and/or reconstructing the situation, known as *redirection* or *reconstruction* actions. It might also move the field in a new direction from a totally new starting point. At this case the action is considered *re-initiation* level of contribution.
iii) *Paradigms that attempt to 'integrate' multiple current paradigms, reflecting convergent thinking, called 'paradigms-integrating' contributions.* There are also subcategories within each category. Actions combine approaches, where actions are categorised as *convergence* or *integration*.

7.6.2 Critical Observations on Identification of Creative Qualities

According to the identification of the quality of *creative contribution* for each design action occurring (in the reasoning process and the reflection-in-action with the interim products), there are *qualitative differences* that distinguish the role among design actions in idea generation and concept development throughout the whole design process. It is important to point out that the boundaries

[89] See Chapter 4 to view the segmentation and coding scheme to identify the gradual transformation of mental imagery through sketching episodes influenced by the propulsion theory (Sternberg, 2003).

between the categorised qualities in Sternberg's model of eight types of creative contributions (1999; 2003) are not cutting edges. For example, 'forward incremental' quality represents either a small step forward or a substantial leap, while 'reinitiation' restarts a subfield, and so forth.

In the 'reinitiation*'* type, a field or subfield reaches an undesirable point or has exhausted itself moving in the direction that it is moving to when new information is introduced to the original field. Rather than initiating a design action that moves the field or subfield towards in a different direction from where it is (as in the 'redirection' type), the designer may suggest moving to a different direction from a different point in the multidimensional space of design. A creative architect most often questions his/her assumptions and starts over from a point that most likely makes different assumptions. This creative quality may lead to a drastic paradigm shift in the design process (see Table 7.5 showing Sternberg's definition of the eight types of creativity (2003: 128-129 and 138).

In another context, the designer may face a conflict between two emerging ideas when new information is introduced to the original idea. This incongruity may cause confusion into how to develop the design concept forward, which affects the qualities of creative contribution of both ideas in the subsequent design process. On the distinction among creative qualities, Sternberg clarified that:

'The scale of eight types is intended as closer to a nominal one than to an ordinal one. There is no fixed a priori way of evaluating amount of creativity on the basis of the type of creativity' (Sternberg, 1999: 129).

In the 'reinitiation*'* type, a field or subfield reaches an undesirable point or has exhausted itself moving in the direction that it is moving to when for example new information is introduced to the original field. This phenomenon, known as *cognitive dissonance*, may be experienced in the reasoning process while thinking of the next action to develop the design concept.[90] Rather than initiating a design action that moves the field or subfield towards in a different direction from where it is (as in the 'redirection' type), the contributor (architect) may suggest moving to a different direction from a different point in the multidimensional space of design. The creative architect most often questions his/her assumptions and starts over from a point that most likely makes different assumptions. This creative quality may lead to a drastic paradigm shift in the design process (see Sternberg's definition 2003: 138).

7.6.3 Evaluation of the Integrated Analytical Approach

The objectives of integrating quantitative and qualitative approaches in a joint framework are fivefold:

First, this joint approach correlates the qualitative and quantitative descriptions to identify the most critical actions in the design process. It detects and demarcates the *sudden mental insights, eureka* and *aha events* in the linkograph's structure. It also detects the quality of creative contribution for the evolving actions in the design process by investigating the context of reasoning.[91]

Second, it identifies the relation between the design contents and reasoning structure through both approaches to arrive at reliable and precise results, which reveal the role of the evolving creative insight in the subsequent events as making the design process either hierarchical or transformational.

[90] This phenomenon is known in the field of creative cognition as *cognitive dissonance*. The phenomenon was first introduced by Festinger (1957) who pointed out that a 'mental conflict' occurs when assumptions or prejudices are contradicted by new information. He showed that when one is confronted with challenging new information, most people seek to preserve their current understanding of the world by rejecting, explaining away, or avoiding the new information or by convincing themselves that no conflict really exists. Meanwhile, a fixation effect may occur, which may result in the halt of the entire design process. It is nonetheless considered an explanation for attitude change, which explains the resistant attitude when we are challenged by what we hold most closely.

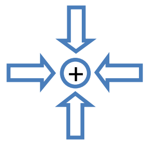
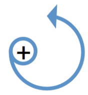
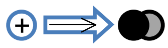
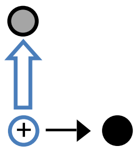
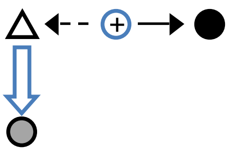
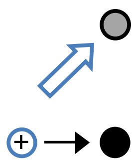
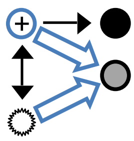
[91] Chiang (2006: 2) says: 'According to several preliminary observations, design eureka functions more likely as an effective act of changing the problem landscape into become more plausible for forming solutions, rather than as an effective solution per se. In this light, "changing-problems" instead of "solving-problems" holds the key to the design eureka. Problem reformulation requires insightful perceptions that can be molded by diversified resources, sometimes are dubious heuristics, hybrid ideas, or even irrelevant analogies. In the hierarchy of design thinking, design eureka plays at strategic level that gives instructions to the lower level of design operations, and is affected by the designers' intentions/philosophies from the level at above.'

Third, it supports our investigation into Goldschmidt's hypothesis 'A' of productivity (1990, 1992, 1995, 2014) and Kan and Gero's hypothesis 'B' of entropy (Kan and Gero, 2005a; 2005b; 2005c, 2008, 2009a; 2005b; 2009c; Kan et al., 2007; Gero et al., 2011) discussed in Chapters 4 and 5. Regarding Kan and Gero's assumption of detecting critical actions and creative insights via Shannon's information entropy, the results of this empirical study pointed at both high and low entropy values. We argue that Kan and Gero's hypothesis cannot be applied in every case of evolving creative ideas where the phenomenon of sudden mental insights is excluded from this generalisation. We would rather support the argument that associates the quantitative identification of the creative insight with the added value to the design process and final product and to identify the quality of creative contribution. In our opinion, the association between creativity, productivity and richness of ideas is still quite questionable in the context of *architectural design* and *thinking process*. The pioneer architect may draw a few lines to come up with an unpredicted novel design concept and thus Kan and Gero's assumption is refuted.

Fourth, it detects two main parameters to identify the qualities of creative contributions for the evolving actions: reframing the solution versus restructuring the design problem.

Fifth, the *aha* moment occurs when the architect realises what the question of design is about. A spectrum of creative contributions is derived and categorised in gathering a wide sample of design experiments. The *hyper-stimulation* phenomenon of the *false aha* may occur in thinking, which causes diversion in idea generation. After critical evaluation, the designer may return to the former idea and abandon the false aha, or generate a new idea by creating synthesis with any of the preceding ideas. The transition from one frame of reference to a new one is addressed in Akin and Akin (1996).

Table 7.5 Sternberg's taxonomy of creative qualities and contribution of design actions

Category	Type	Description	Sternberg's Illustration
Types of creativity that accept current paradigms and attempt to extend them	**Replication** (Stationary mode)	The contribution is an attempt to show that the field is in the right place. The propulsion keeps the field where it is rather than moving it. This type is represented by stationary motion, as of a wheel that is moving but staying in place.	
	Redefinition (Circular Motion)	The contribution is an attempt to redefine where the field is. The current status of the field thus is seen from different points of view. The propulsion leads to circular motion, such that the creative work leads back to where the field is, but viewed in a different way.	
	Forward Incrementation (Forward Motion)	The contribution is an attempt to move the field forward in the direction it already is going. The propulsion leads to forward motion.	
	Advanced Forward Incrementation (Accelerated Forward Motion	The contribution is an attempt to move the field forward in the direction it is already going, but beyond where others are ready for it to go. The propulsion leads to forward motion that is accelerated beyond the expected rate of forward progression.	
Types of creativity that reject current paradigms and attempt to replace them	**Redirection** (Divergent Mode	The contribution is an attempt to redirect the field from where it is toward a different direction. The propulsion thus leads to motion in a direction that diverges from the way the field is currently moving.	
	Reconstruction, Redirection (Backward Divergent Motion)	The contribution is an attempt to move the field back to where it once was (a reconstruction of the past) so that it may move onward from that point, but in a direction different from the one it took before. The propulsion thus leads to a motion that is backward and then re-directive.	
	Reinitiation (Reinitiated Motion)	The contribution is an attempt to move the field to a different as yet unreached starting point and then to move from that point. The propulsion is thus from a new starting point in a direction that is different from the one the field previously pursued.	
Types of Creativity that merges disparate current paradigms	**Integration** (Convergent Motion)	The contribution is an attempt to integrate two formerly diverse ways of thinking about phenomena into a single way of thinking about a phenomenon. The propulsion thus is a combination of two different approaches that are linked together	

Source: Sternberg, 2003: 128-29.

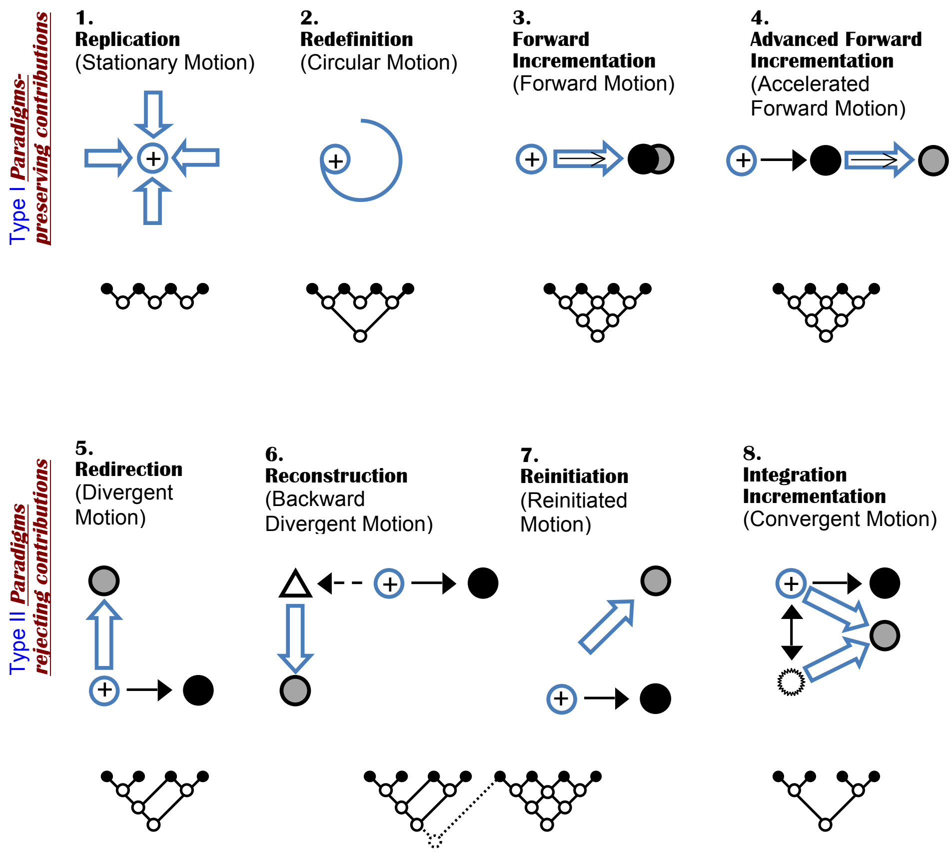


Figure 7.27 Configurations of linkography for each quality of contribution

7.7 In Conclusion

This chapter presented detailed descriptive analyses of three architectural design cases to design a *Cheese Factory*, with specified functional requirements, programme and constraints. Three experienced architects were invited to participate in this empirical study. Ethnographic observations and designers' retrospective comments were provided while describing the actions occurring in each design process, which led to detecting the evolution of creative concepts, identifying the critical actions (insights) and their role in the reasoning process.

According to the results of empirical study of Chapters 6 ('unstructured' design experiment) and 7 ('structured' design experiment), we conclude that the evolution of critical actions and creative ideas that contribute to the formation of novel concepts can occur within either *incremental* reasoning or *insightful* thinking process. Sudden mental insights cause paradigm shifts if *an unprecedented idea occurs, restructures the design problem and redefines the set of goals, provided that it adds value to the final product and the whole design process*. The drastic change can be distinguished by investigating the relations among the subsequent products following the sudden insight, and its value overall.

We conclude that this empirical study reveals that design is a *hierarchical* process when problem-solving is based on *procedural* components to execute the concept and generate the solution through systemic actions. Procedural components are *stage-based* and *problem-oriented*, and neglect contextual aspects that are associated with the reflection-in-action in the design situation: no matter what the design situation is, the solution is generated according to a certain actions in the designer's mind. The components are based on abstraction and analysis of the problem structure that leads to making a choice from a pool of generated solutions. They are primarily based on the formulation of a solution-neutral problem statement, and indicate that the final design should be dependent on logical deduction rather than experience. Common to all problem-oriented design processes, these characteristics form the basis of procedural components.

In other cases, design is a *transformational* process when the generation of ideas is based on *contextual* components and *affordances to the environment* taking into account reflection-in-action to transform mental imagery from one state to another. Contextual components are *action-centric*, where designing the situation under practice is based on 'content-based' decisions, which address the way designers perceive, recognise and experience the problem. Addressing the aspect of the designer's perception of the emerging problem, identification of the interim goal and generation of possible action for the next step reflects the core nature of design activity and reflective practices in which there is a shortage of procedural components. Looking only at the overall components of largely content-based decisions limits the power of the incremental reasoning and procedural components. A design process may comprise both procedural and contextual components, differing from one situation to another. Procedural components emerge while solving the parts in the design process (details of concept) while contextual components distinguish the overall structure. Both components are detected via the configurations of a linkograph.

The quantitative approach aimed to identify the nature of hierarchical structure and depth for the networks of relations for each action occurring using integration and centrality measurements, while the character strings of information evaluated complexity, rate of information and probability. We conclude that there are two types of structure from which creative insights evolve: *deep structure* (actions dependent on the preceding ones), or *shallow structure* (actions independent from the preceding ones). Total independence shows no relations at all of backlinks with the preceding actions in the linkograph, which may reflect the case of drastic change occurring provided that the value of the new design concept is addressed in the reasoning process and in the subsequent decisions and final artefacts. In Chapter 8, *directed linkography* is an objective tool to examine the role of design moves, critical actions and creative insights in the result of procedural and contextual components in the reasoning process, while we aim in Chapter 9 to identify the synthesis processes in each case.

7.8 Key Findings of Chapter 7

- This study describes the experimental linkography research. The design process of this type of structured brief comprises *procedural* and *contextual* components where the former appear while designing the parts and the latter appear while dealing with the whole. Both components affect the definition of the goals and problems and idea generation throughout the design process. The design process takes a different state with the sudden occurrence of mental flashes.
- The validation of the proposed descriptive method is achieved through the correlation between quantitative and qualitative results.
- Considering the epistemology of practice and aspects of design situation while describing the evolution of ideas and formation of concepts is crucial to understanding the nature of creative discovery in design processes.

Chapter

8 *Directed Linkography* and *Syntactic Analysis*: The Role of Critical Moves, Eureka Insights and A-Ha Moments in the Structure of Reasoning Process[92]

This chapter introduces a new method of looking at evolving design moves and critical actions by considering the time of emergence in the structure of the reasoning process. Directed linkography compares quantitative and qualitative analysis of actions occurring in two different situations: the first is synchronous, looking at relations back to preceding events, and the second is diachronic, looking at the design state after completion. This study reports on the emergence of creative insights in the architectural design process. Using detailed ethnographic observations of designers working on an architectural design task, and coding these using linkographs, we identify two poles of design creativity: incremental improvement and the sudden creative insight. Our aim is to show how these can be identified in the structure of the linkograph to reach better understanding of the conditions under which creativity and innovation take place.

There has been great interest in design research in interpreting the relation between reasoning and the emergence of creative insights. *Linkography* is a modelling tool widely used to represent the relations between segments of the design process and to code the *dependency* relationships between them. It is seen as a *multilevel hierarchical structure* comprising *pivotal* nodes. Many attempts have aimed at quantifying critical moves occurring during the design process. Goldschmidt, on first introducing linkographs (1990), developed a *link index* model indicating a measure for *critical* moves and design *productivity* (Goldschmidt, 1990, 1991). Kan and Gero adopted Shannon and Weaver's *probabilistic theory* (1949) and related the *richness* of design to *entropy* measures based on the hypothesis that creative events are related to *uncertainty* and *surprise* (Kan and Gero, 2008, 2009a, 2009b, 2009c; Gero et al., 2011). A model was developed more recently by El-Khouly and Penn (2012b) to describe the design process based on qualitative and quantitative analyses.[93]

Linkography is directed to the time of emergence of design utterances. It is characterised as a pivotal structure of a multilevel hierarchical network. A quantitative model is proposed to capture the structure of events and sudden changes occurring in the design process using syntactic measures of space syntax and urban graphs. Two situations are compared: synchronous designing using 'directed linkography' looking at the backlink relations and the completed state of the linkograph. Local and global measurements and directed j-graphs are correlated with design contents and descriptions for the concept development.

Our interest lies in capturing events of drastic change and investigating the transformation of the associated interim products. Such events are hypothesised, reflecting significant transformation in concept reasoning and the configuration of the linkograph. Through this model, we aim to answer the question: *why would sudden insights divert the network to a different structure state*?

In this chapter, syntactic and network analyses are adopted to characterise multilevel networks in linkographs using *depth* and *centrality* measures to deduce the structure beyond the emergence of creative insights. Different types of insights are investigated with the aim of revealing the structure of reasoning in design processes: *incremental* insights versus *sudden* breakthroughs. *Directed linkography* quantifies the network of relations that is created for each node with the preceding events. It looks at the *backlink* relations only and compares the results with the global network. Justified graphs (j-graphs) are used to represent the structure of each utterance that emerges and to enquire whether insights appear within *shallow* or *deep* networks. We ask, *why would an insight with a shallow structure transform to become deeply structured*? *What is the impact on the design process and generation of solutions after this transformation*? The value of this investigation is pertinent to proposing research methods and models to reveal the *formation of novel concepts* and *human creativity* in the design process.

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[92] Elements of this chapter were first presented by the author at the Ninth International Space Syntax Symposium, Seoul: Sejong University, 2013 (El-Khouly and Penn, 2013).

[93] El-Khouly and Penn (2012a) first introduced the method of character strings of information, known as 't-code' measures, to quantify the linkograph by computing three measures: 'complexity', 'entropy' and 'information content' for each design node. T-code string measures compute only the bottom level of direct relations that are made at each node sub-network (un-hierarchical measure), where syntactic analysis measures 'depth' for the structure. For more insights on this method, see Chapter 5.

This chapter aims to develop a descriptive model that compares *synchronous* and *diachronic* situations of emergence that takes the fourth dimension of 'time' into consideration, to define the role of the sudden emergence of mental insights on reformulating the relation between the *form* and *function* in design process, to define a variety of configurations of sudden insights in light of the context of relations with the *preceding* and *following* actions, to explain the *correlation coefficients* between the quantitative measurements for a variety of design situations in light of the qualitative analyses of Chapters 6 and 7, and to explain a method of how to read the significances of linkography networks in relation to a variety of modes of *creative cognition* of design thinking. In Figure 8.1, the concept and structure of a proposed computational model is outlined for this purpose in accordance with the proposed method and findings of Chapters 6 and 7.

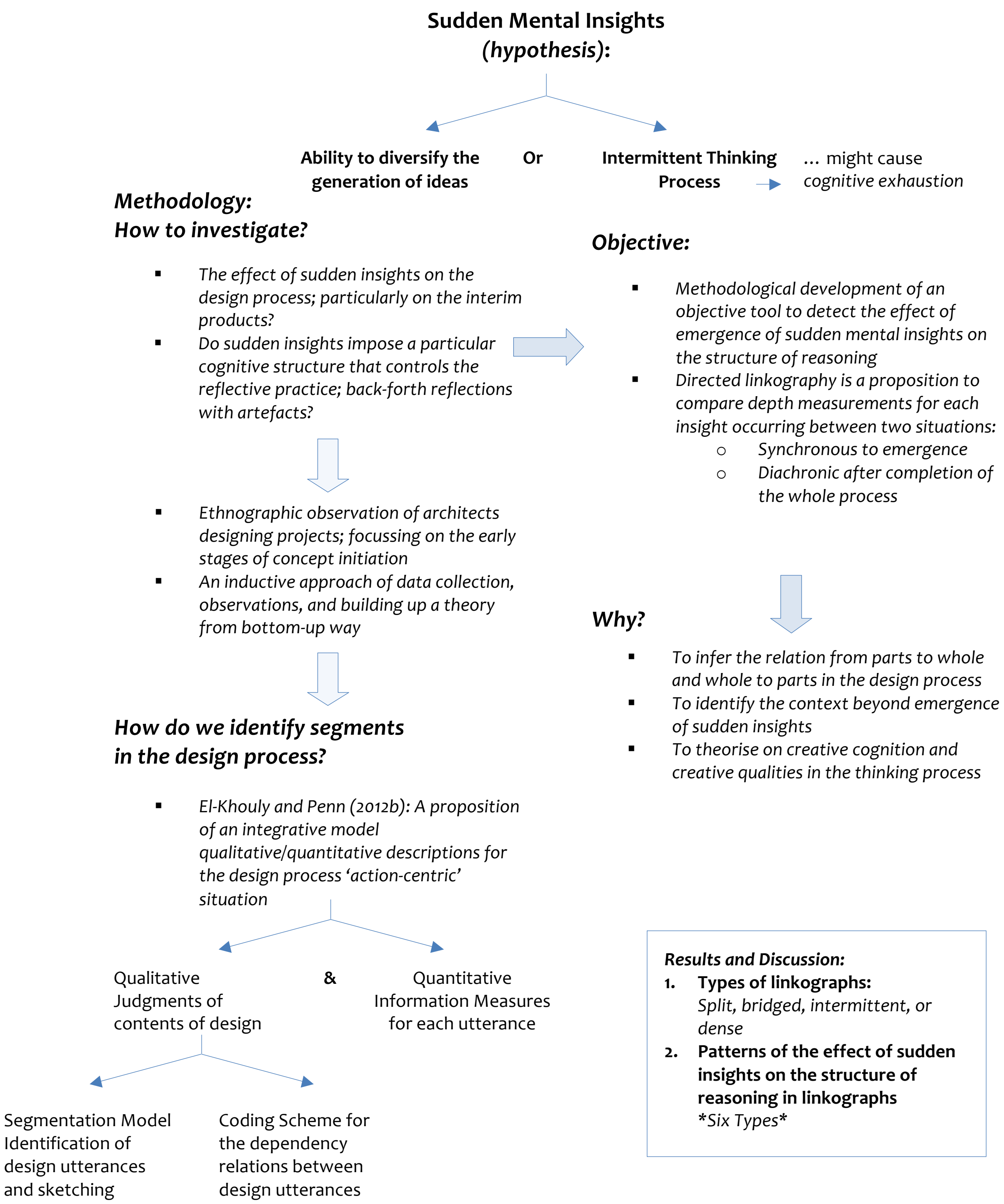


Figure 8.1 Concept and structure of the proposition of computational model

8.1 Background
8.1.1 Creative Insights and Design Reasoning

Serious attempts to provide a taxonomy of design action include the proposal of Suwa et al. (1998a, 1998b) to classify design actions into four macroscopic levels: physical, perceptual, functional and conceptual. However, our concern in this study lies with reasoning in design with the aim of investigating the context behind the emergence of creative insights. We propose two categorical modes: incremental and non-incremental. *Incremental* reasoning provides a consistent route to preserve an initial conceptual idea by structuring the process of development through a sequence of interrelated steps. The concept is dependent on retrieving knowledge from preceding events and providing details through transformations of the earlier idea. Creative insights emerging in this context reflect a discursive and/or systematic type of development that can be interpreted as providing the ability to reframe the initial solution. *Non-incremental* reasoning provides an investigatory approach that provides diversity to explore ideas and the ability to restructure the design problem and reintroduce the whole situation. Creative ideas appear as *sudden mental insights* or *breakthroughs* emerging unpredictably in the design process.

The *incremental* view argues that *stimulus responses* are retrieved from memory and structured by a 'trial-error-correction' design approach (Weisberg, 1986), reflecting the *rational* paradigm of the 1960s. We assume that Hillier's (1996) principle of design echoes the logical approach of Popper (1963) and Simon (1969). Hillier considers design to be a knowledge-based process, structured by knowledge, with architects as social programmers. The *non-incremental* view argues that design problems are solvable through *rapid cognitive restructuring* and creative ideas emerge from within an *insightful*, *unconscious* and *discontinuous* context. Once an insight is realised, the problem solver can quickly implement its solution (Metcalfe and Wieße, 1987; and see also the Gestalt school).

Types of insights can be distinguished in different ways. Insights are either dependent on memory to retrieve good ideas, or they rely on *unconscious actions* beyond awareness. Two points pertinent to the emergence of insights are investigated in this chapter by using syntactic analysis: whether (1) incremental insights appear in a shallow network of relations, with many direct links within the linkograph (indicated by high integration value, low mean depth and real relative asymmetry [RRA]), or (2) sudden insights are deeply structured within the linkograph (indicated by low integration value, high mean depth and RRA). The proposed method aims to reveal the structure of the network for each creative insight, configure the patterns in linkographs, and identify the contexts of the emergence of insights.[94]

8.1.2 Capacity for Creative Thinking

Goel (1995) distinguished two types of transformation of ideas in the design process. *Vertical* transformation develops the initial concept by adding more details to it; *lateral* transformation changes the existing concept to explore new ones, leading to a *divergent* style of thinking. Divergent thinking is an essential *capacity* for creativity (Robinson, 2010). *Intelligence* requires certain types of deductive reasoning and divergence helps to build good arguments. To think laterally is to be able to see many ways to interpret a question, not just linear or convergent ways, and to see multiple answers rather than just one (ibid.).

Convergence causes integration and cohesiveness between those ideas (Kan et al., 2007). *Interconnectivity* and *diversification* formulate the configuration of linkographs and significances can be illustrated. On the one hand, if a sequence of moves is very integrated, in an extreme case it could lead to a saturated state: a fully interconnected pattern. Saturation reflects premature engagement with a prevailing concept, undermining design novelty and reducing chances for creative insights. A strong association with a particular concept causes *fixation* and can be a *hindrance*. On the other hand, high diversification could lead to a disconnected linkograph: variant ideas are irrelevant, sparse and segregated, and no converging ideas are taking place in the process, lessening the chance of progression. A *balanced* state, however, reflects *homogeneity* of design forming a structured process. A structured linkograph states a creative process and shows the probability of novel ideas transpiring. Different

[94] *Diversification* of links of ideas can be accounted for through entropy measures, diversifications of cognitive actions as well as from following the cognitive scheme of Suwa et al. (1998a, 1998b). RRA values account for *associativeness* among linkography networks and nodes. Design process can then be examined in terms of patterns of moves' association.

linkographs were tested and characterised according to the configurations that are shown in Figure 8.2 through syntactical and character strings t-code analysis (El-Khouly and Penn, 2012a; and see Chapter 5).

We argue that sudden insights reflect a 'subconscious' process of the brain, whereas incremental insights reflect 'conscious' actions. Archimedes' 'Eureka!' moment, and many significant discoveries and breakthroughs in history occurred while the inventor was occupied in a different context doing something else. Conscious actions are reflected by the interrelated chunk of patterns in the linkograph resembling a direct dialogue with the sketch. Sudden insights emerge when the unconscious action collides with the conscious state giving the advantage of incubation; a longer period of incubation makes the collision more effective in disconnecting the linkograph.

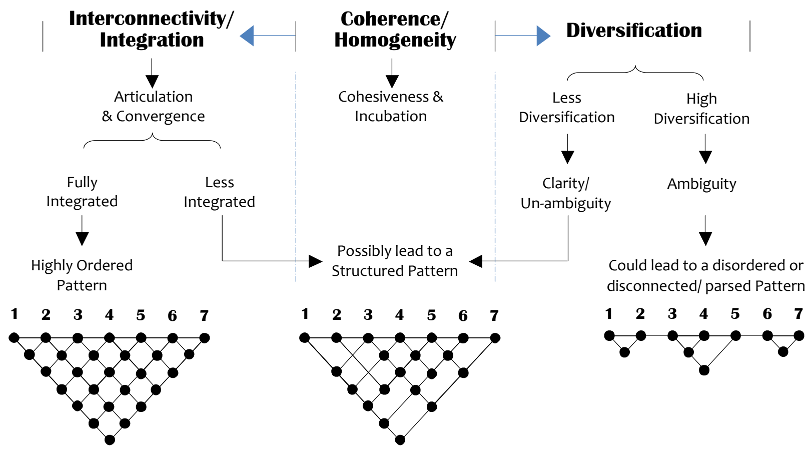


Figure 8.2 Implications of convergence vs. diversification on the configuration of linkographs

8.1.3 Identification of Sudden Insights: '*Eureka*' and '*Aha*' Moments

A sudden mental insight moves perception from its current situation to a different independent state. To identify the emergence while designing, lateral transformation from one *sketching episode* to a totally different one is proposed to reflect the transformation of perception occurring in the mind, where each episode reflects a certain conceptual idea. From detailed ethnographic observations of designers it is apparent that reflecting on earlier design sketches while designing the current one plays an important role in allowing unpredicted glimmers of inspiration to suddenly occur.

Multiple exchanges of ideas between different artefacts and media stimulate the emergence of sudden flashes. Architects demonstrate specific idiosyncrasies while designing, such as *back/forelinking*, recycling an idea between different projections, tracing drawings, zooming in/out, verbalisation and using confirmation words, signs and gestures, body/hand language, annotations and scribbles. All actions were transcribed, coded for linkography, and investigated for any sudden insights occurring while preparing a detailed analysis for each design experiment.

The identification of sketching episodes to construct the linkograph in our model accords with the following propositions: Schön's (1963) definition of the 'invention and evolution of ideas' as 'treating the new in terms of the old', 'a displacement of ideas from the old situation to new one'; Koestler's (1964) conception of 'bisociation', which distinguished routine skills of thinking on a single plane ('single-minded') from the creative act ('double-minded'); Goldschmidt's definition of a design 'move' (1994) as 'a step, an act, or an operation that transforms the design situation relative to the state in which it was prior to that move'; Akin and Akin's (1996) identification of 'sudden mental insight' as 'any sign on perceiving a notion to break out a frame of reference and shift to a new one'; Csikszentmihalyi's (1996) definition of the 'creative process' as 'flow and the psychology of discovery and invention'; and Johnson's (2010) conception of a 'good idea' as two thoughts colliding, one that has incubated for a long time in the mind with another arising from the present situation.

8.1.4 Coding *Dependency* Relations

Design moves are coded based on two sets of creative contribution (Sternberg, 2003): actions that 'preserve' continuous reflections with the mind, and actions that 'defy' continuous reflections. *Preserving* reflection proceeds on the initial concept taking various forms of activity, such as *replication*, *redefinition* or *advanced incrementation*, in the same design state. *Defying* reflection introduces a new item to the design state. It has a different taxonomy of actions to change the design situation: *divergence, synthesis* and *reconstruction*. This model is built on the range of transformations that a design idea is susceptible to. Creative insights are determined and judged according to this qualitative framework. Figure 8.3 gives snapshots of the coding processes between sketching episodes.

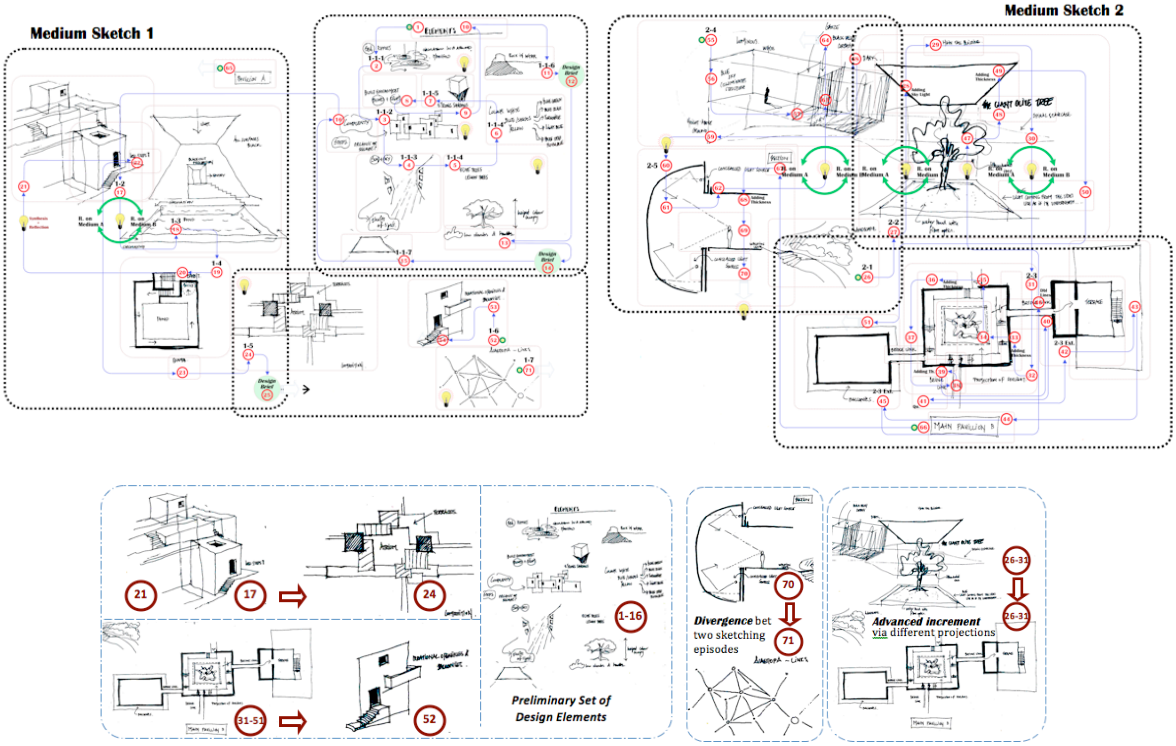
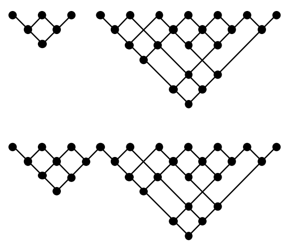


Figure 8.3 Snapshots of coding different sets of drawings and sketching episodes to capture the structure of reasoning: taxonomy of creative qualities

8.1.5 *Linkography* is a Configuration of *Pivotal Structure*: *Bridging Nodes* as *Creative Hinges*



We argue that radical paradigm shifts occurring during the design process most probably cause splits between the patterns of the linkograph. The transformation of ideas and emergence of insights are forms of paradigm shifts. If sudden flashes occur rapidly, the structure of the design process, the design problem and the conceptual idea are subject to a drastic change. The whole situation might be restructured, seemingly causing *disconnecting* or *bridging* nodes in the linkograph's pattern.

Rapid disconnections reflect a scattered process between different subsets of ideas while bridging is a *synthesis* process. A linkograph containing pivotal nodes of transformation is able to represent the state of coherence and structure, endorsing aspects of creative thinking: (1) *unexpected discoveries* as *unintended consequences and surprises that keep the design exploration going in reflective conservation with the situation* (Schön and Wiggins, 1992); and (2) *reinterpretation dialogue* between '*seeing that*' and '*seeing as*', which correspond to *reflective criticism* and *analogical reasoning* (Goldschmidt, 1991, 1994). These aspects of the creative process are considered as driving forces to explore novel ideas. Introducing *discontinuity* into a previous concept is a key factor in creative problem solving (Weisberg, 1993). Therefore, such critical actions are matters of investigation enquiring into causes of discontinuity in the linkograph.

Some of the most observed factors are the multiple exchanges of ideas between different products and back/fore linking. The processes of unexpected discovery and reinterpretation split the linkograph into separate networks that can be connected via bridging nodes. We argue that the importance of a linkograph lies in its configuration of such pivotal nodes to reveal the creative moves in the design process. The configuration between sub-networks in the linkograph takes any of the following relations: *overlaid interrelation*, *intersection* or *sparse* (see Figure 8.4).

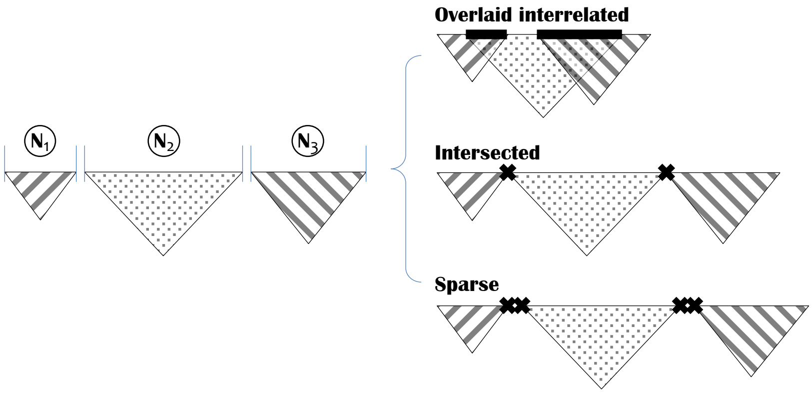


Figure 8.4 Configurations for possible relations between sub-networks in the linkograph

8.2 Paradoxical Point: *Local* versus *Global* Measurements

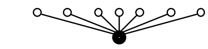
Two situations are compared in this study. The first considers the *time of emergence* for each segment in the linkograph by looking at the *backlink* relations with the preceding vertices on a *local* level, while the second ignores the time factor and concatenates *back* and *fore* relations for each vertex to process depth measures at a *global* level over the whole linkograph. The first situation is *directed* linkography, which processes measures at each network (node) synchronous to the emergence. The second is *undirected* and explains the diachronic impact of insights after the completion of the whole linkograph, with the preceding and following actions. The paradox resulting throughout this comparison is when one vertex gives two drastically deviated values from local to global levels for the same design content. What does the reasoning design imply for two different integration values for one single action? We extend the enquiry into: *are sudden insights likely to occur in highly structured or shallow networks*?

Relevant to this context, our motive for using different measures to quantify the linkograph is to characterise its multilevel hierarchical structure. Perplexing results are observed after processing syntactic and character string t-code measures on different cases; impulsive values do not follow a firm rule. Moreover, the correlation between syntactic and t-code measures are seen to be inconsistent.[95] What has been revealed is that each measure indicates a different structure state of the linkograph. While t-codes demonstrate merely direct relations created at the bottom level of structure, syntactic (*depth*) measures characterise the multilevel hierarchy, taking into account all matrices of relations between vertices while weighing the sub-network for each. Thus, we conclude that syntactic and t-code measures are incomparable.

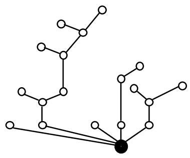
Concerning the emergence of insights, we argue that an insight imposes a certain structure on the following actions in the design process according to its content. Once a fixation has occurred, the designer attempts to break out of that frame of reference by generating a new insight or solution and shifts to another one. This explains the evolution of thoughts and interim artefacts along the process. Directed linkography provides an objective tool to weigh the linkograph via either syntactic or t-code measures. It assesses the value of those insights occurring at an early stage that are either thrown away or are useful for synthesis at final stages of design. Whether generated based on the preceding actions as *advanced* or *sudden incrementation*, the applications of different measures are important in order to distinguish different characteristics of insights and linkographs from different levels. Two roles for the structure of network are derived:

[95] The applications of *character string t-code measures* (t-complexity, t-entropy and t-information) are explained in detail in El-Khouly and Penn (2012a, 2012b).

1. High integration → low mean depth (MD) → low relative asymmetry (RA) → a shallow system



2. Low integration → high mean depth (MD) → high relative asymmetry (RA) → a deep system



Both types can be detected through j-graphs. Shallow and deep structures reflect different states of incremental reasoning and dependency on the preceding actions, but a disconnected structure might enable sudden insights to occur. A sudden insight occurs when high diversification between thoughts takes places instead of cohesiveness and incubation. The emergence of insight is beyond human awareness. By introducing this tool, we aim to reveal the context of reasoning behind the emergence: whether it is dependent on the precedent or not.

8.3 A Computational Model for Time-Driven Linkography

8.3.1 Principles for 'Scripting'

- **Segmented Archiography and Justified Graphs**

A justified graph (j-graph) is a method used in space syntax for analysing spatial configurations. An initial space, usually an entrance, is placed at the bottom of the graph (the *root space*) and all spaces directly connected to the root (one syntactic step away from root space) are placed one level above and connected to it by lines. All spaces directly connected to the first level (two syntactic steps away from root space) are placed on a second level and connected to the first level by lines and so on. The resulting graph displays a visual representation of the *depth* of the layout of spaces.

Justified graphs offer a visual picture of the overall depth of a layout seen from one of its points. A tree-like justified graph has most of the nodes many steps (levels) away from the bottom node. In such a system the mean depth is high and described as deep.

- **Conceptual Framework for a Computation Model**

In this model, we focus on the characteristics of the linkograph to build the conceptual framework of computation. Linkography is segmented for each utterance occurring. A cascade of matrices are extracted for each utterance in the graph, once for the backlink relations (directed graph) and another for the concatenated backlinks and forelinks altogether in one matrix (undirected graph). *Depth* and *centrality* measurements are computed for each network (matrix), a correlation is then compared overlaying the first set of backlink relations with the second set of concatenated strings to reveal if any drastic event occurred causing a drastic change in the network. Correlation with qualitative judgements on sketching episodes and creative qualities of design utterances are then followed to identify creative sudden insights, design '*eureka*' events and '*aha*' moments. Figure 8.5 presents the conceptual framework for this proposition.

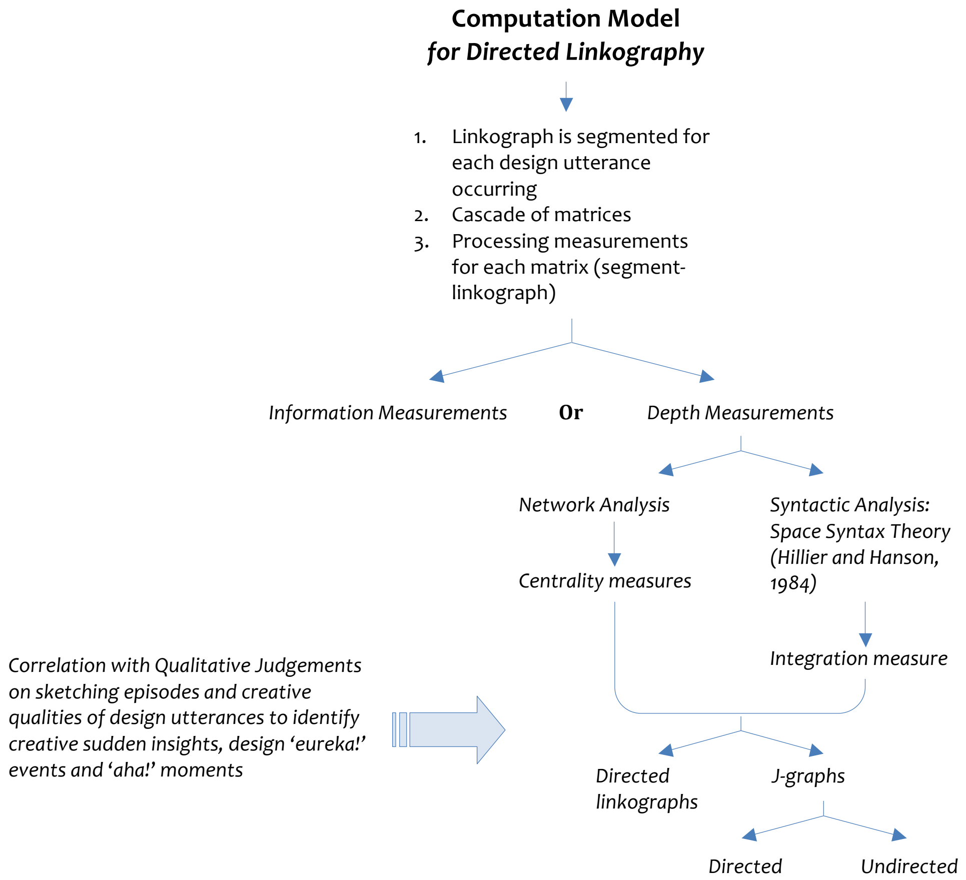


Figure 8.5 Conceptual framework for the proposition of computation model

8.3.2 Application of *Syntactic* Integration Measures to look at '*Directed*' Graphs

This method can be used to compare two situations in the design process: one concurrent to the emergence of nodes and the other retrospective, looking at the whole linkograph after completion. In the following cases, *local* and *global* measures are applied to the linkographs. Before embarking on the analysis, a number of common features are first demonstrated providing insights into the quantitative method:

1. Each node has $(n_i - 1)$ possible values if we look forward to the rest of the graph based on the position '*i*'. The design process is a hybrid of 'conscious' and 'unconscious' actions; the trajectory of development cannot be determined or predicted in advance to reshape the final design. Our interest at this stage is therefore directed to the *backlink* relations reducing possibilities to a minimum.
2. We must be aware that the starting point has no *back* relations and is abandoned from the estimation (flattened) as well as nodes 2 and 3 if fully linked. Fully saturated networks deliver no RRA values.
3. The local measure for the end point is itself the global measure for the whole system since the linkograph is completed, looking back at all the preceding actions (directed to time).

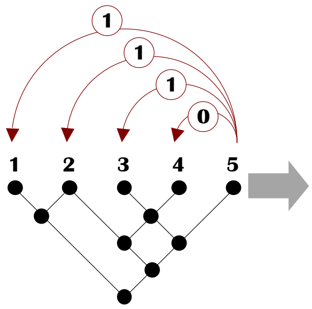
This section introduces the estimation method of syntactic measures to quantify linkographs to the community of design research. For a linkograph network of five nodes, formed on the following relations:

- Vertex 2 has one backlink relation to 1, thus (2> 1).
- Vertex 3 has no backlink relations with nodes 2 and 1, (3≯ 2, 1).
- Vertex 4 has two backlink relations with the preceding actions 3, and 2, thus (4> 3, 2) and (4≯ 1).

- Vertex 5 has three backlink relations with the preceding actions 3, 2, and 1, thus (5>3, 2, 1) and ($5 \not> 4$).
- Estimating the syntactical measures *integration*, *betweenness* or *closeness centrality* takes into account the relations amongst all vertices in the estimation process for vertex 5, 4, 3, 2 and 1, which can be extracted into a two-way matrix presented in Figure 8.6a.
- According to the j-graph for node 5, the *depth* ' for this node equals 5 and the *mean depth* MD = D/(n-1)= 5/(5-1)= 1.25
- Integration can be estimated from the following equations:

  - Integration = 1/real relative asymmetry RRA
  - RRA = real asymmetry RA/relativised real asymmetry RA_d
  - RA = $2(MD_i - 1)/(n-2)$ → 'n' is the size of system
    - RA = 2(1.25 – 1)/(5-2) = 0.17
    - RRA = 0.17/(0.352) = 0.47
    - Integration at node 5 = 2.13

- However, the string of information for node 5 is: '1110' comprising backlink relations to nodes 3, 2 and 1 with no relation to node 4, knowing that the computation of string t-codes resembles the basic level of direct relations in a multi-level structured system. The extraction method is illustrated also in Figure 8.6a.
- If the system of relations at node 5 changes slightly, avoiding the relations of ($5 \not> 3$) and ($5 \not> 2$) for instance, the linkography of Figure 8.6b gives a slightly different j-graph but a significant difference for the integration value. In this case RRA = 1.42 and integration for hypothetical node 5 = 0.7.



	1	2	3	4	5
1		1	0	0	1
2	1		0	1	1
3	0	0		1	1
4	0	1	1		0
5	1	1	1	0	

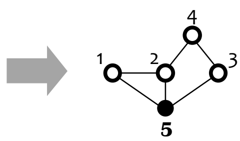
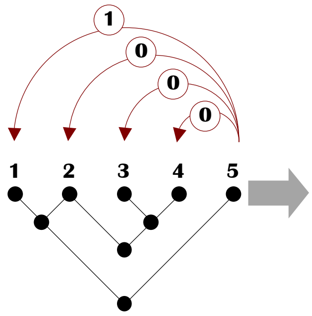


Figure 8.6a Two-way matrix of relations for the whole system requisite to process syntactical measures for node 5, the j-graph, and the extraction of string of information prior to computing t-codes



	1	2	3	4	5
1		1	0	0	1
2	1		0	1	0
3	0	0		1	0
4	0	1	1		0
5	1	0	0	0	

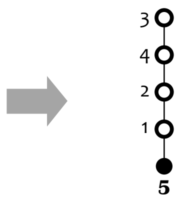


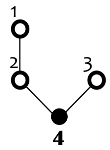
Figure 8.6b Two-ways of relations for a hypothetical system for node 5 based on avoiding two relations with preceding nodes, the j-graph, and string t-code – integration value changes drastically

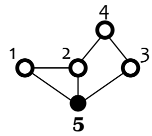
The estimation of depth at each node is based on backlinks (j-graph); depth measure is estimated for the shortest number of steps required to go from one vertex to the other vertices in the network. See Figures 8.6a, 8.6b and 8.6c, which illustrate examples of depth measure for the linkographs in using directed estimation. Figure 8.7 illustrates a model to compute the cascade of directed archiography and j-graphs.

- ***Depth* Measure for Directed Justified Graphs**

1) Application to Figure 8.6a:

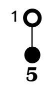
- Node 2: has only one backlink to node 1, (2> 1), depth of one level only is required to go from node 2 to node 1, thus depth for node 2 equals 1 step.
- Node 3: has no backlink relation to nodes 2 or 1 and thus the network of this node is flattened with zero depth.
- Node 4: has backlink relations to nodes 3 and 2 but no relation with 1; however, to go to node 1, the steps required have to be counted through node 2 since node 2 has a direct relation to node 1, thus depth for node 4 equals: 1+1+2 = 4 steps.
- Node 5: has backlink relations to nodes 3, 2, and 1, but has no direct relation to node 4. However to go to node 4, there are two shortest step ways, whether via node 2 or node 3 with 2 steps required. Thus, the depth for node 5 = 1+1+1+2 = 5 steps.

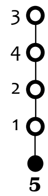




2) Application to Figure 8.6b:

- The hypothetical case of Figure 8.6b gives totally different depth measure. For the directed graph of node 5, it has one backlink direct relation to node 1 with no direct relations to nodes 4, 3 and 2 (knowing that any forelink from node 1 is not counted in our estimation for the backlink directed graph). Thus, depth of the directed graph for node 5 equals 1 step.
- However, the estimation for the global depth measure for node 5 can take into account all back and forelink relations in the estimation process. Thus, node 5 has one direct relation to 1. However to go to node 2, 2 steps have to be taken via node 1. To go to node 4, three steps have to be taken via nodes 1 and 2. And finally to go to node 3, 4 steps have to be taken via nodes 1, 2, and 4. Thus the total depth of the undirected network for node 5 equals: 1+2+3+4 = 10.





3) Application to Figure 8.6c:

- Figure 8.6c is a linkograph with 21 vertices. Node 15 is the highly connected overall. Generating the j-graph for backlink relations for node 15, directed RRA value = 0.127, and directed integration = 7.87, which constitutes a very high value and reflects a highly ordered shallow system. At this case, node 15 is not expected to be reflecting sudden insight; it is highly linked to most of the preceding vertices (78.5%) that is explained by very low probabilistic entropy.

To conclude from these examples:

1. Syntactic measures reflect the complexity of the linkograph. Depth measure quantifies the sub-network of relations for each vertex within the whole. String t-codes reflect the basic level of the direct relations only.
2. Syntactic measures capture the structure of events and detect any slight changes occurring in the flow of the network of relations better than t-codes. Thus, the structure of reasoning beyond the emergence of insights is revealed.
3. A cascade of matrices is extracted for each vertex (design move) in the linkograph, once for the backlink relations (directed graph) and another for the concatenated backlinks and forelinks altogether in one matrix (undirected graph). This method is shown in Figure 8.7 to extract and compute the j-graphs for each design move.

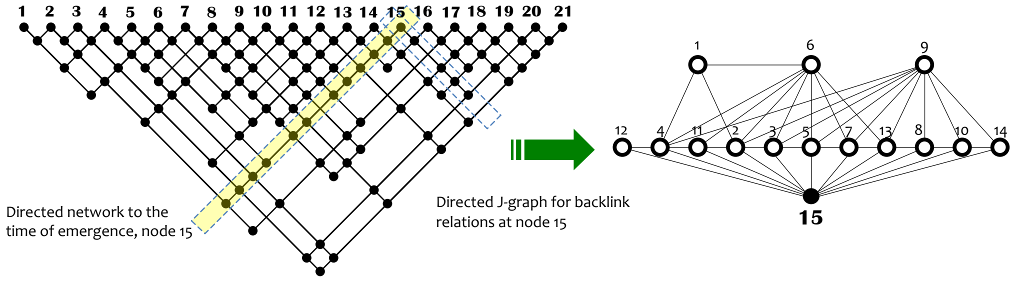


Figure 8.6c Backlink-directed j-graph for node 15 – highly connected in the linkograph

- ***Network* Analysis: *Centrality* Measurements for Linkographs**

The relative importance of any vertex within a network can be determined through *centrality* measures. It provides an indication of how important (well-used) the vertex is within a network. In the analysis of linkographs, the following can be used:

- **Depth** is the natural distance metric between all pairs of nodes, which is defined by the *length of their shortest paths*. The farness depth for a node is the sum of its distance to all other nodes in the network. High depth reflects a deep structure.
- **Closeness centrality** is a measure of how long it will take to spread information from a vertex to all other nodes sequentially. It is considered the inverse of the farness depth; the more central a node is, the lower its total distance (depth) from all other nodes.
- **Betweenness centrality** quantifies the number of times a node acts as a 'bridge' along the shortest path between two other nodes. It indicates the control of a human on the communication between other humans in a social network (Freeman, 1977). Vertices that are predicted to occur on a randomly chosen shortest path between two randomly chosen vertices have a high betweenness.

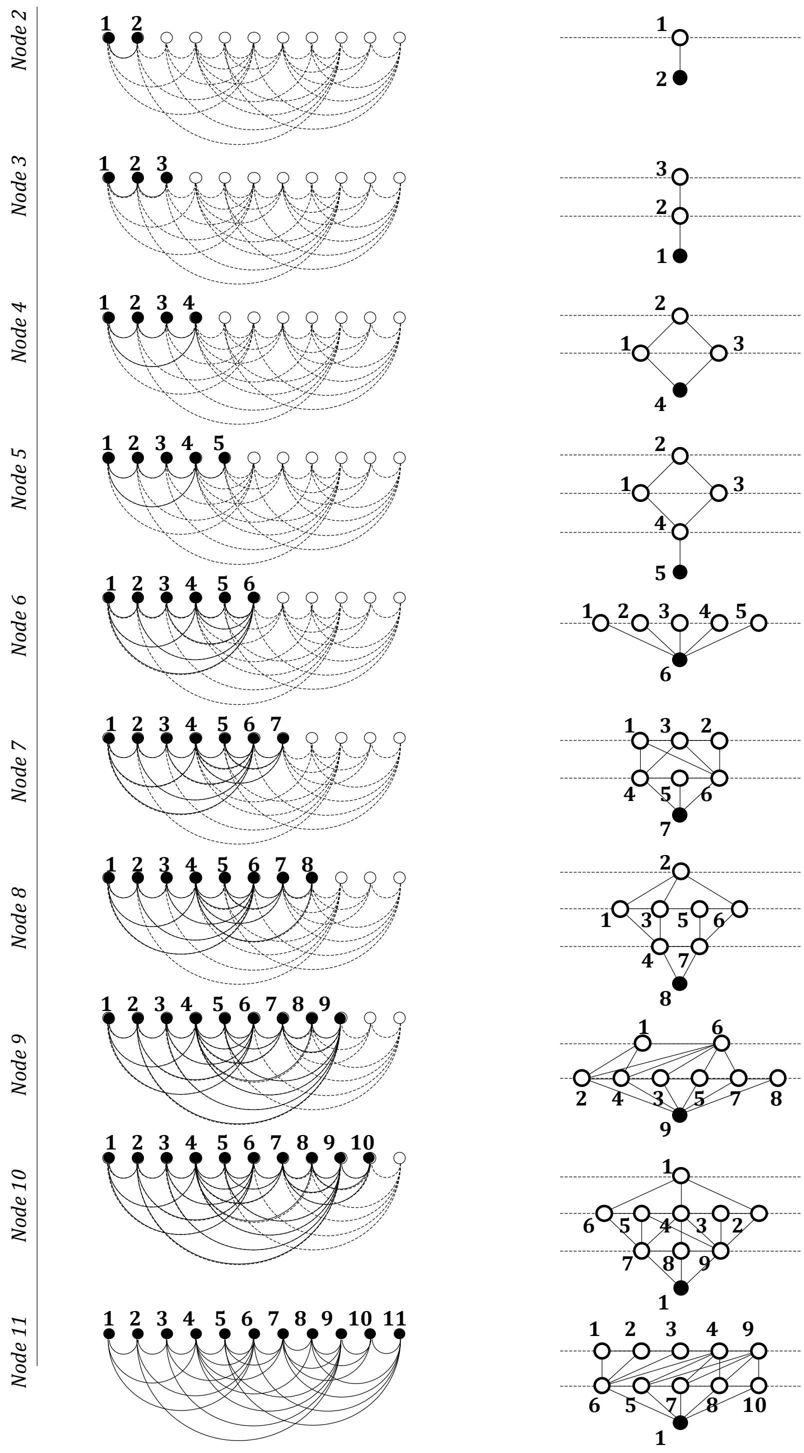


Figure 8.7 Processing cascade of directed archiography and j-graphs

8.4 Applications to Architectural Design Processes

Our proposition makes an association between *qualitative* and *quantitative* analyses to evaluate design *novelty*, based on capturing the structure of events in the linkograph and correlation with design contents: *actions* and *interim products*. Directed linkography describes the design process in light of qualitative descriptions of *concept development* and *dependency* between *sketching episodes*. The aim is to provide an objective tool to detect the *emergence of insights* and describe various *modes of reasoning* and *formation of concepts*. *Reliability* of this model is assured by examining the *segmentation* process, *dependency* codes and *identification* of insights with the *quantitative* outcomes in a cyclic framework to arrive at self-regulation.

In the following section six cases demonstrating different states of design are described applying directed linkography. The task is to design '*A Pavilion for your country at Expo Shanghai 2010*' within a one-hour time limit. The brief is unstructured giving the designer free rein. Video protocol, serial order of sketching, and the architect's retrospective comments are transcribed and coded. Applying directed linkography, the following results may be presented.

8.4.1 Case Study 1: Unstructured Brief – Expo Pavilion

- **Designer 1**

  - ***Qualitative Description***

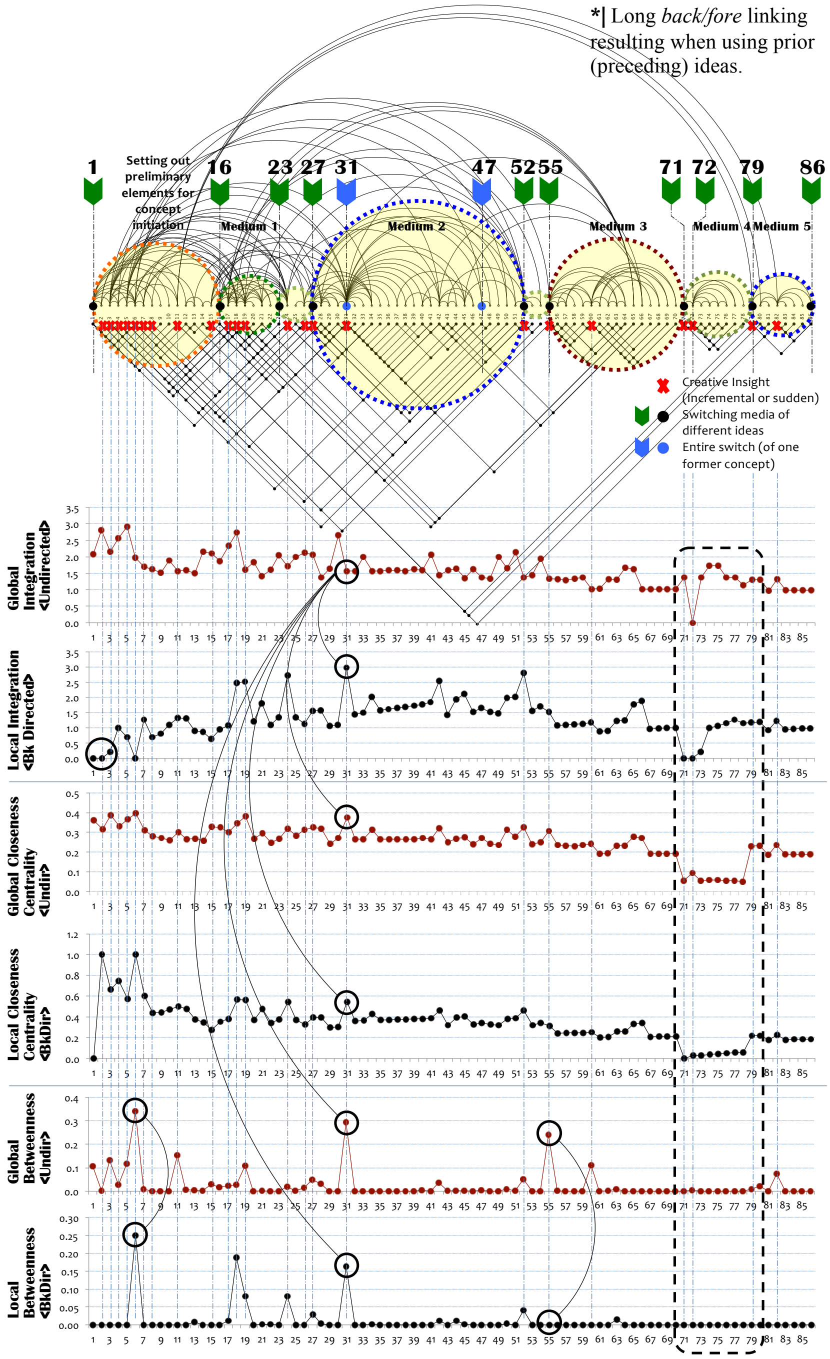
This design case represents the Greek pavilion and addresses conceptual elements such as: 'sunlight and shadows', 'complexity of interlocking masses', 'trees and bushes', 'blue sky', 'sea ripples', 'rounded circulation', and 'rocks in water'. The process started insightfully, sketching each element independently. Each insight was then recalled to form a concept. Five pavilions were congregated in one master layout.

The fourth pavilion is a sudden change occurring on the prevailing stream. The concept is independent, representing 'immigration of Greeks' all over the world. It caused disconnection in the linkograph with no relation to the preceding or following events. This is a unique event, distinguished within the structure by applying directed linkography. Figure 8.8 presents the computation method processing directed versus directed measures. Figures 8.9a and 8.9b present directed and undirected j-graphs.

- ***Syntactic Analysis and Annotation of Linkograph***

1| Node 6: is highly linked with the preceding events and was detected via directed betweenness as a bridging vertex. Its content is a derivation of the colour scheme, based on the previous conceptual insights and was recalled thereafter to develop other ideas in the process.

2| Identification of sudden creative insights is based on qualitative judgements of the transformation of ideas via interim artefacts; not on quantitative bases. However, overlaying results gives the way to assess our joint model by investigating a significant correlation between quantitative and qualitative analyses.



5| A representation of the multiple switching positions of media and exchanges of thoughts via sketches and the relation their relation to foster stimulation of unprecedented sudden insights of ideas' solutions.

6| Syntactical analysis is able to precisely detect "semi" or "fully" disconnected patterns in the linkograph better than t-code string measures; either via "undirected" or "directed" means.

7| Bridging nodes are represented through betweenness centrality measures. The results are correlated with our qualitative judgement of identification of the creative insights; assuring objectivity of the model and high match between the quantitative and qualitative outcomes.

8| The system is flattened at the early beginning of the process giving zero real relative asymmetry RRA values.

9| Although integration and closeness centrality are inversely correlated with depth, however some significant nodes delivered inverse correlation between both measures.

3| Node 31 is an example for a highly connected vertex that represents shallow structured system with relatively median global (undirected) integration but high directed integration value that reflects the role of this node on the following actions after the emergence. Other bridging nodes are also stated via betweenness centrality measures. Both directed and undirected betweenness give precise results accord with our identification of the pivotal nodes.

4| Node 55 is an example giving different values of betweenness centrality results between directed and undirected methods. The emergence has a significant impact on structuring the following process that resumed until a new insight has emerged on the flow. It became a bridge transferring preceding knowledge to a new medium sketch, however it wasn't yet bridging on emergence since directed betweenness equals zero.

Figure 8.8 Annotation of quantitative measures over linkography (undirected contrasted to directed values), (Case Study 1, Designer 1)

- ***Contrasting Directed and Undirected J-Graphs for Creative Insights***

This section compares directed and undirected j-graphs and investigates the context of the network behind the emergence of sudden insight. See Figures 8.9a and 8.9b for this case study.

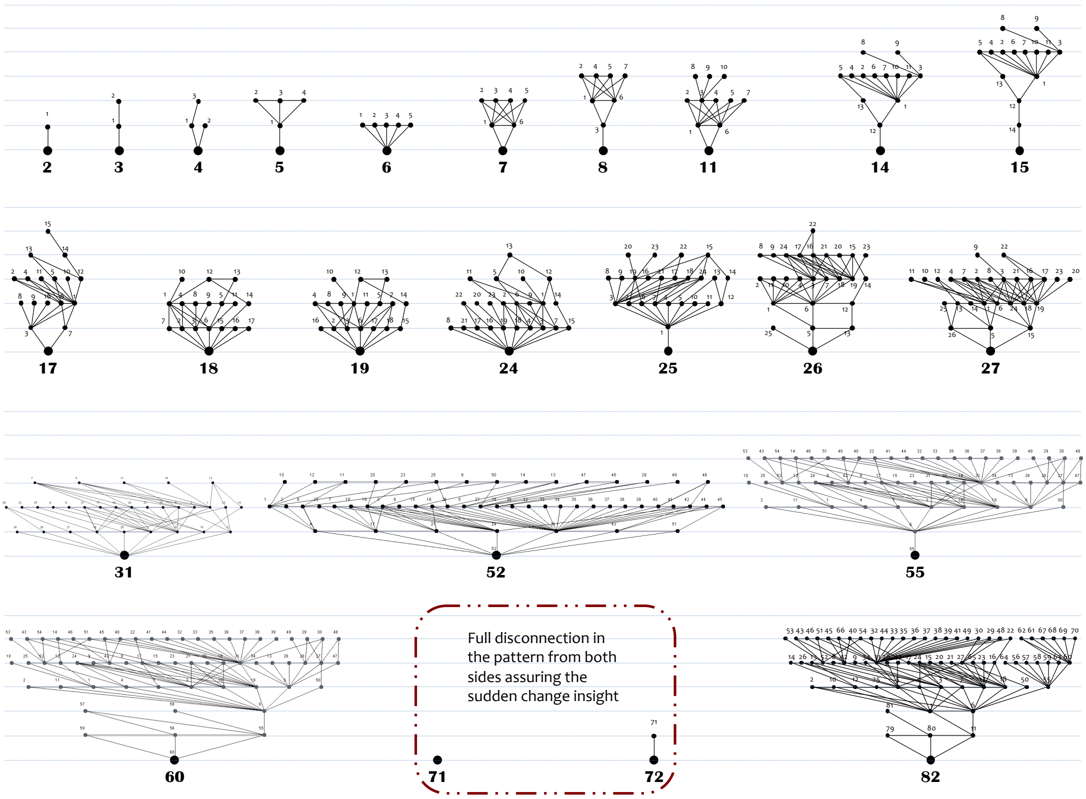


Figure 8.9a Creative insights represented by directed j-graphs for backlink relations (Case Study 1, Designer 1)

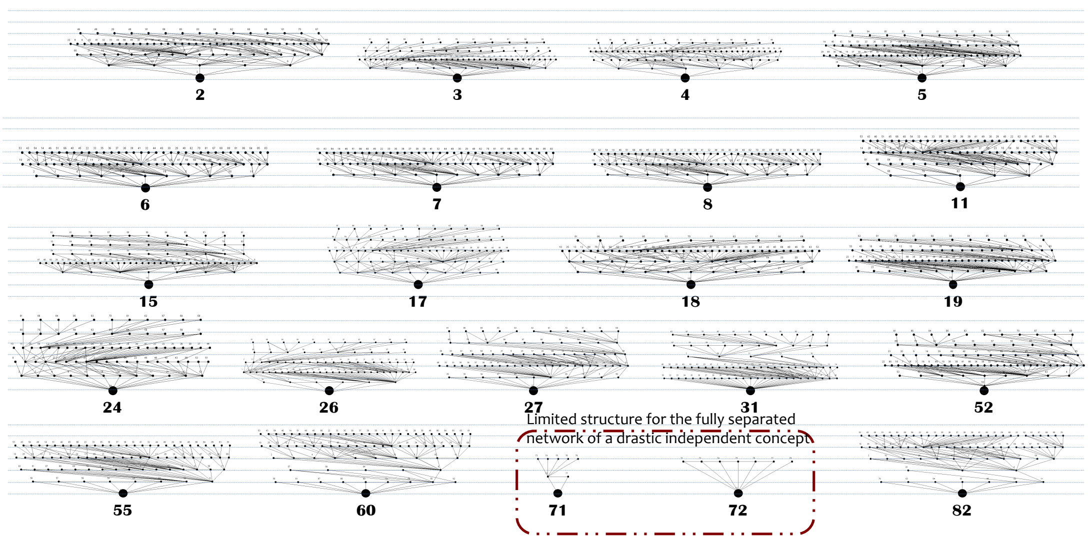


Figure 8.9b Creative insights represented by undirected j-graphs, concatenation of back and forelinks (Case Study1, Designer 1)

- **Designer 2**

    - ***Qualitative Description***

This design case represents the UK's pavilion and addresses conceptual elements such as: 'diversity of British society', 'life and sports', and 'science and history of the empire'. The process started insightfully then ideas were recalled in one site-plan sketch. The transformation happened through bridging nodes. Figure 8.10 presents the computation method processing directed versus directed measures. Figures 8.11a and 8.11b present directed and undirected j-graphs.

- ***Syntactic Analysis and Annotation of Linkograph***

1| Node 16 is the highly connected vertex in the whole system. It represents the starting point of a new sketching episode after articulating some independent conceptual elements for the design idea at the first medium (nodes from 2:15). At node 16, the designer congregated the forms of the concept initiation phase to the new site plan sketch. It is a clear example of a bridging node, an insight that has emerged as knowledge transferred between different media sketches. This is a bridging node that linked preceding events with following. It has high directed as well as undirected integration values that reflect shallow network with low mean depth and real relative asymmetry.

2| Equally integrated systems (of similar size) are observed for the series of nodes 19:24, then for the series of nodes 27:36, where each series reflects actions that were held in a certain medium sketch. Values are almost identical on directed and undirected scales for integration, closeness centrality, and for betweenness centrality.

3| The system is flattened at the early stage of the process. It is fully connected for the first three nodes giving zero RRA values.

4| Median systems deliver average on all measures (on balance to the whole network and to the directed measurements), which simply means that it is neither deep nor shallow in absolute terms.

5| Betweenness centrality:
Quantifies the number of times a node acts as a 'bridge'. Nodes 13, 16 and 25 represent three different cases when comparing directed and undirected results.

Node 13 bridges backlink relationships with its previous nodes with a relative value on back-directed betweenness measures; however, its effect on the following nodes is almost negligible according to the undirected measure. It is then bridging on a local level not on a global network.

Node 16 is an example giving different values of betweenness centrality results between directed and undirected methods. But it is considered a 'bridging' vertex since directed and undirected measures indicated its effect. The impact has increased from 0.2 on the directed scale to reach 0.6 on the undirected scale. This means that this node has a crucial role in transferring a certain idea and on structuring the following process and the overall system. It supports our hypothesis that the emergence of some creative insights could have a significant impact in some cases so as to structure the design actions. The insight imposes a structure of design concept on the following actions to the extent of binding the interim products to a particular transferred idea. This result has been checked with our qualitative model by judging the relations between the interim sketches before and after the emergence of each creative insight and was found to match.

Node 25 is a different example. The emergence has a significant impact on the following process and is considered to be a bridge transferring preceding knowledge to a new medium sketch. However, it isn't yet bridging on emergence since the directed betweenness equals zero while the undirected scale shows a value of 0.4 overall.

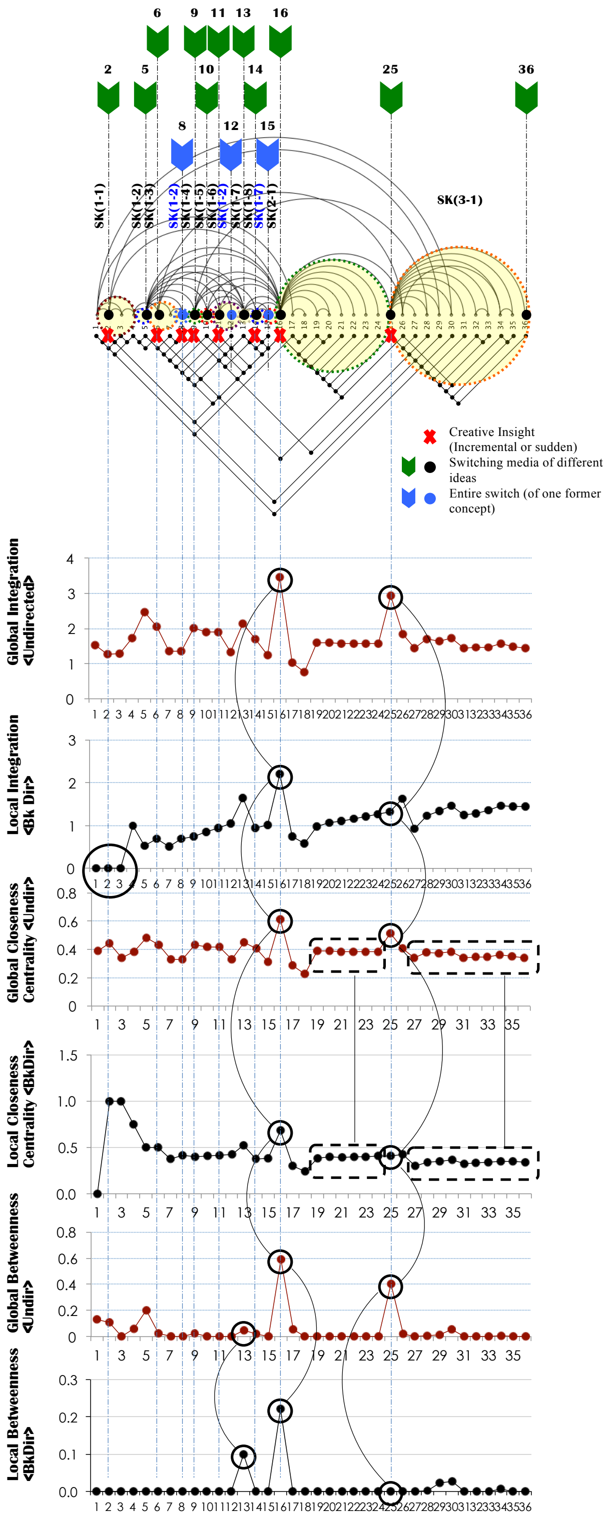


Figure 8.10 Annotation of quantitative measures over linkography (undirected contrasted to directed values) (Case Study1, Designer 2)

- ***Contrasting Directed and Undirected J-Graphs for Creative Insights***

This method can be extended to compare directed and undirected j-graphs and investigate the context of the network beyond the emergence of sudden insight. See Figures 8.11a and 8.11b for this case study.

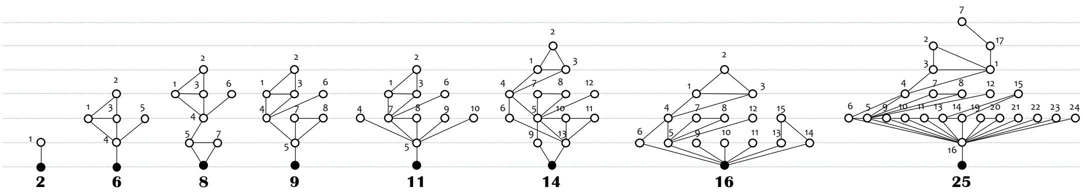


Figure 8.11a Creative insights represented by directed j-graphs for backlink relations (Case Study 1, Designer 2)

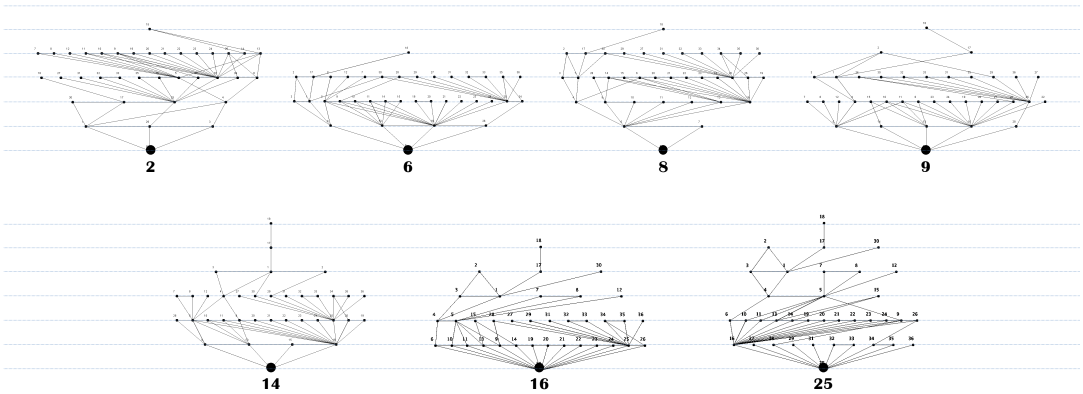


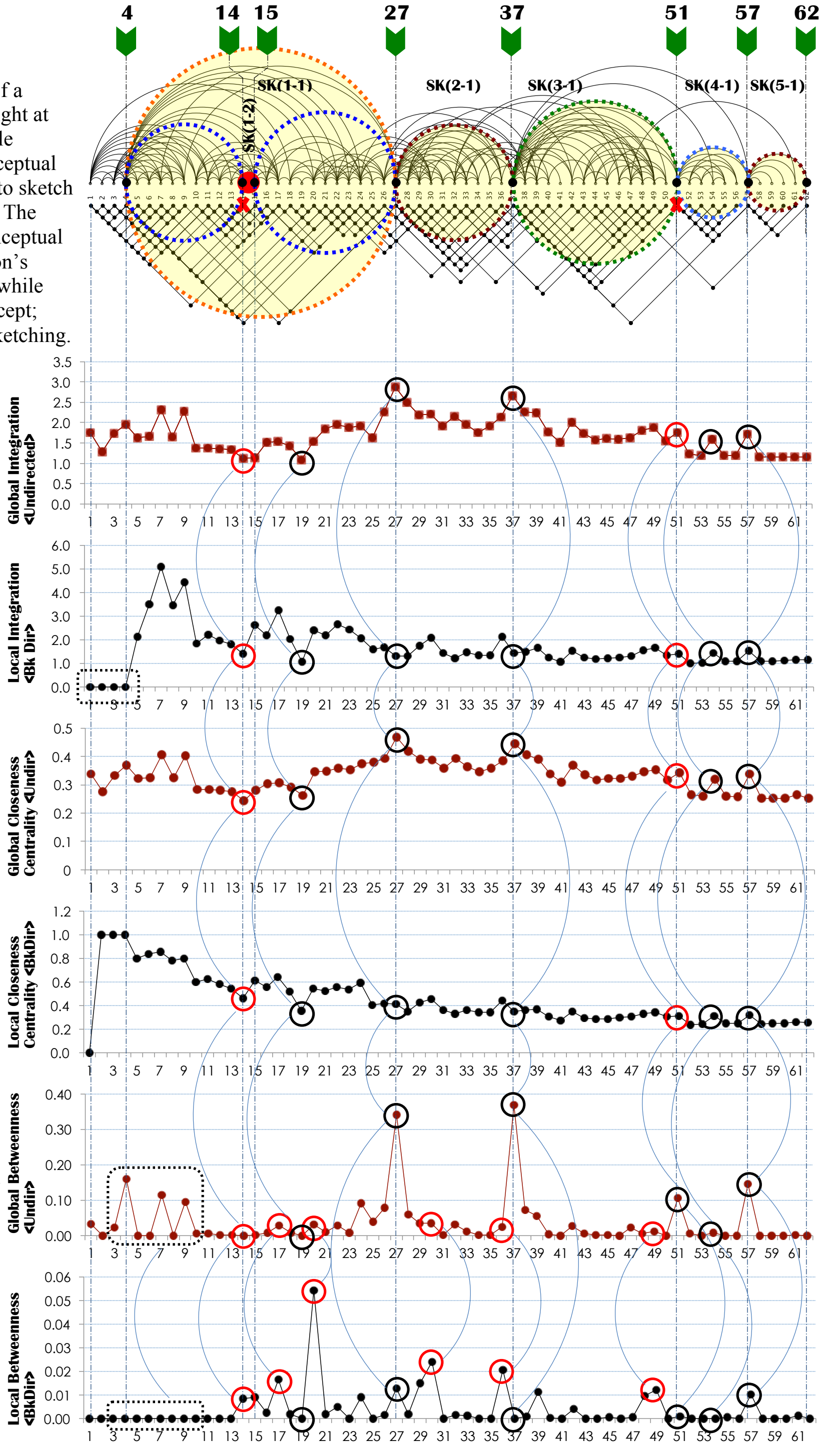
Figure 8.11b Creative insights represented by undirected j-graphs, concatenation of back and forelinks (Case Study 1, Designer 2)

- **Designer 3**

- ***Qualitative Description***

This design case study represented Egypt's expo pavilion. It was the designer's decision to build the concept based on the *Spring Revolution* of 25 January 2011. The transition from an abstract philosophical idea to the architectural spatial form was only the designer's interpretation of an imaginary vision coupled with extensive freehand sketching work for drawing various projections and enhancing phases with high-calibre personal talent. Figure 8.12 presents the computation method processing directed versus directed measures. Figures 8.13a and 8.13b present directed and undirected j-graphs.

- ***Syntactic Analysis and Annotation of Linkograph***



1| The emergence of a sudden creative insight at node 14 occurs while elaborating the conceptual idea and switching to sketch in another medium. The stimulus for the conceptual form of cross-section's appeared suddenly while articulating the concept; verbalising while sketching.

2| The system is flattened at nodes 2, 3, and 4 for the directed integration measure because it is fully linked reaching the saturation state

3| Closeness Centrality measure shows how long it will take to spread information from one vertex to the other nodes sequentially. It is the inverse of the farness depth; the more central a node is, the lower its total distance (depth) from all other nodes. High closeness value reflects a shallow network with high connectivity.

4| Closeness Centrality and integration are inversely correlated – look at the flips between the two measures at nodes 14, 19, 27, 37, 42, 54 and 57

5| Nodes 27 and 37 deliver high closeness centrality and at the same time both are considered bridging transitional nodes with high connectivity measures

7| This is an incremental design process with a structured pattern, comprising compact chunks of links and overlapping transitioning (bridging) nodes with very few long back/forth linking

8| Balance is monitored between undirected and directed integration values for node 51 that is a creative incremental insight extending the main concept into another level designing the conceptual perspective elevation

9| The change in *betweenness centrality* values for the undirected global measures, nodes 3, 7, 9, 27, 37, 51, and 57 is higher than the case for the directed local measures for the same nodes, constituting the effectiveness on a global manner for those bridging nodes. However, the measures for nodes 17, 20, 30 36 48, and 49 are giving the privilege in opposite for the directed measure, in which constitutes the effectiveness of those bridging nodes on a local level instead. Thus, directed linkography enables us to distinguish the role of any node while comparing values for the local and global networks

6| Nodes 27 and 37 are transitional; bridging different media sketches; 27 switches SK(1-1) to SK(2-1) and 37 switches SK(2-1) to SK(3-1). Information pertained to certain conceptual elements is transferred from the precedent to following utterances. Betweenness centrality directed value is 0.01 for node 27 and zero for 37. Estimating undirected betweenness, values show significant change in both cases; the importance of each node is reflected on the global level only. Thus directed linkography method allows distinguishing the role of the node while comparing locally (directed) versus globally (undirected) measures.

Figure 8.12 Annotation of quantitative measures over linkograph undirected vs. directed (Case Study1, Designer 3)

- ***Contrasting Directed and Undirected J-Graphs for Creative Insights***

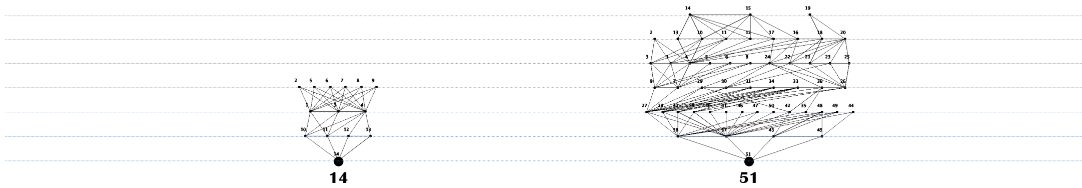


Figure 8.13a Creative insights represented by directed j-graphs for backlink relations (Case Study 1, Designer 3)

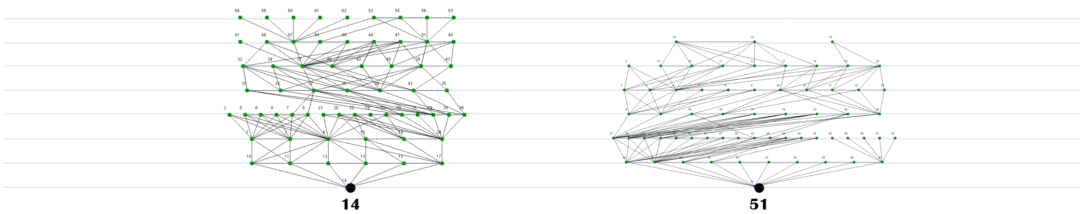


Figure 8.13b Creative insights represented by undirected j-graphs, concatenation of back and forelinks (Case Study1, Designer 3)

8.4.2 Case Study 2: Structured Specified Brief – Cheese Factory

- **Designer 1**

  - ***Qualitative Description***

This design process was built bottom-up in relation to the functional programme assigned in the design brief for cheese factory. Several independent conceptual elements were designed and synthesised to create the concept in the following phases. There were stages of development and knowledge transfer from one medium to another in a creative non-repetitive way with the aim of enriching the design concept. Processing the linkograph with undirected as well as directed network analyses and syntactical measurements highlights insights and bridging nodes before and after the imposition of external constraint in order to investigate the impact of the specified structured design brief on the design process and creativity. Figure 8.14 presents the computation method processing directed versus directed measures. Figures 8.15a and 8.15b present directed and undirected j-graphs.

- ***Syntactic Analysis and Annotation of Linkography***

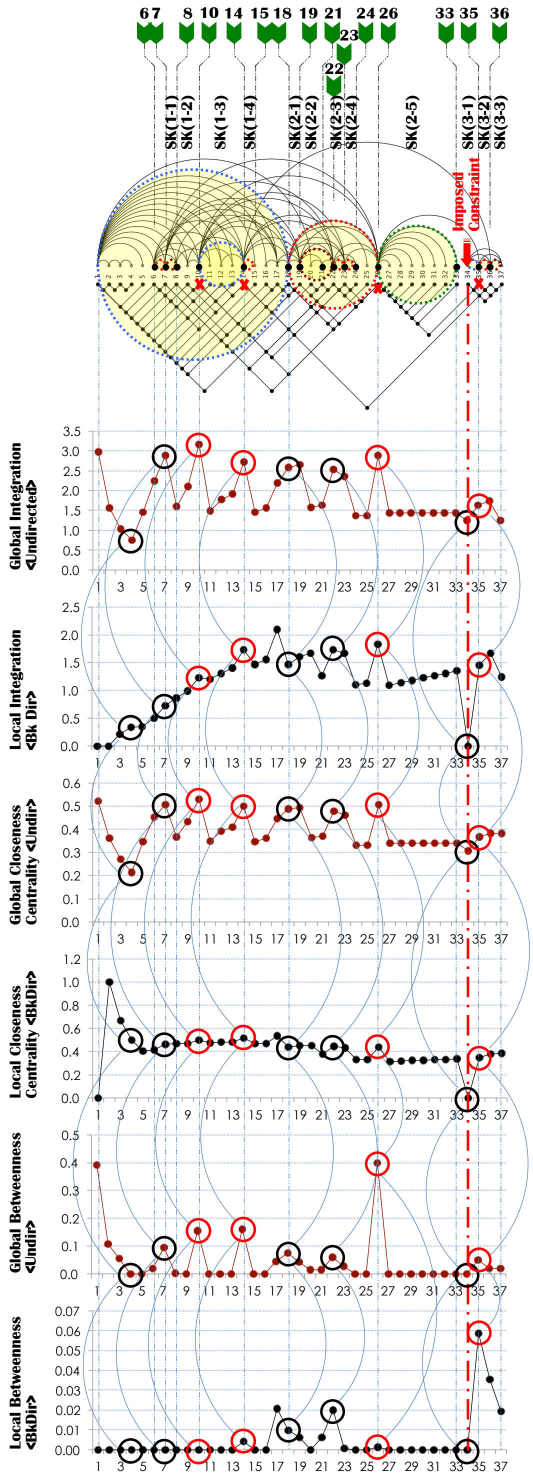
1| Node 4 is at ending side of the network; the link is broken with node 5. It delivers the highest integration undirected value on the global network, however the resulted saw-tooth network with the preceding events reflected an intermediate directed integration value on balance to the other nodes.

2| Node 7 delivers one of the lowest integration values but an intermediate value for the directed local network.

3| Multiple switching media at nodes 6, 7, and 8 flipped undirected integration measure once being semi-shallow network at 8 but deep for 6 and 7

4| Insights 10, 14, and 26 are bridging nodes, 10 switches media SK(1-2) to SK(1-3), 14 switches SK(1-3) to SK(1-4), and 26 switches SK(2-2) to SK(2-5).

5| Betweenness Centrality: Nodes 10 and 14 deliver high undirected values compare to the directed measure which means the importance of both nodes transferring information from the precedent actions to the following medium on the global network.



6| Creative insights 10, 14, and 26 deliver low integration values on balance to the other nodes in the whole system, constituting the deepness of the structure of their undirected networks. Further, directed integration is also delivering low values for the same nodes, and thus their local networks are also structured deeply. From both measures; undirected and directed integration, we deduce that those insights are incremental dependent on the precedent actions, bridging information between different media as it is obviously reflected through the comparison between undirected and directed betweenness centrality measures.

7| The imposition of external constraint has split the local network with the precedents giving zero values for directed measures of integration, closeness centrality, and betweenness. However, it induces the role for the following insight; node 26, to transfer the idea to the following actions, in which can be obviously read through the dramatic increase of directed betweenness centrality value.

Figure 8.14 Annotation of quantitative measures over linkograph – undirected versus directed measures (Case Study 2, Designer 1)

- ***Contrasting Directed and Undirected J-Graphs for Creative Insights***

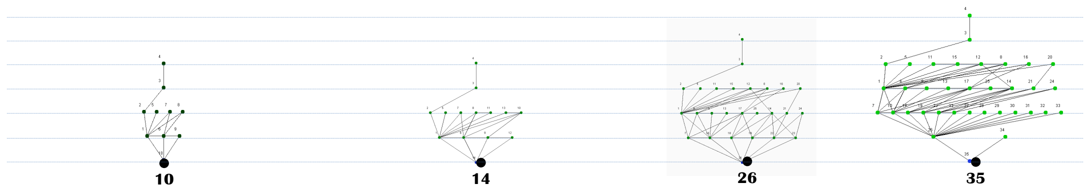


Figure 8.15a Creative insights represented by directed j-graphs for backlink relations (Case Study 2, Designer 1)

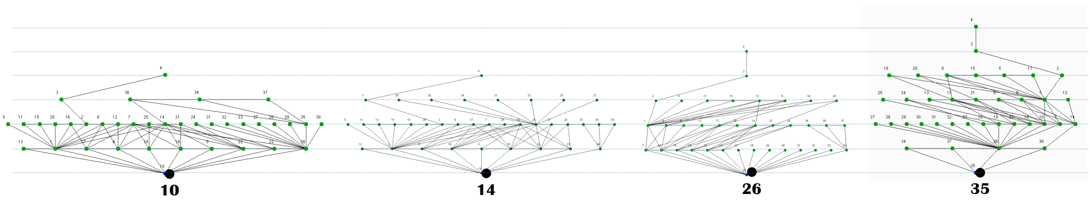


Figure 8.15b Creative insights represented by undirected j-graphs, concatenation of back and forelinks (Case Study 2, Designer 1)

- **Designer 2**

- ***Qualitative Description***

This design process is distinguished by the variety of alternatives that were used, enriching the conceptual idea throughout. Experimenting with different solution alternatives at the initiation phase led to building principles for assessment to evaluate paths of development for the conceptual idea, finding the best solution for the required functional programme. A hybrid solution was developed based on two former alternatives and a proposal for a 3-D perspective was developed accordingly.

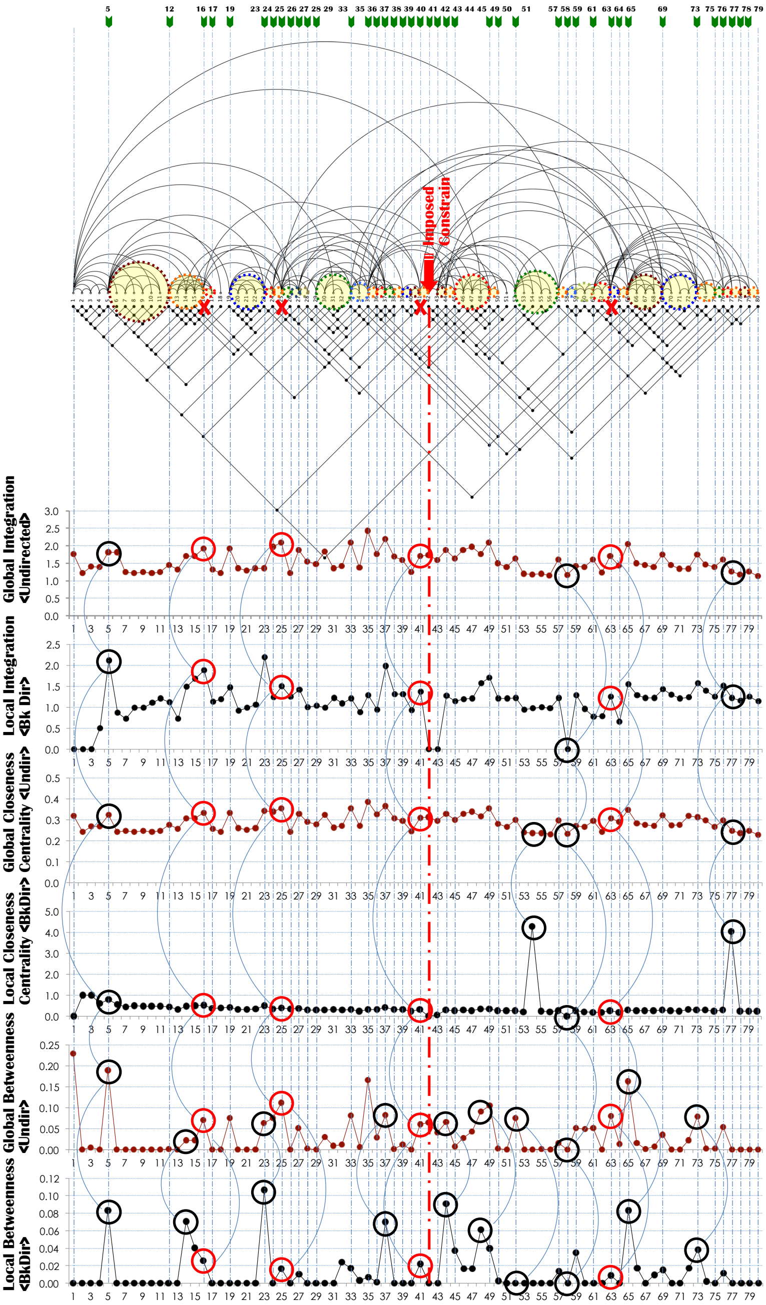
After the imposition of the external constraint on the prevailing flow of design, and despite the disruption and dispersion experienced for a few steps, the designer succeeded in synthesising the new element with the elements of the initial idea maintaining the stability of the early concept. Figure 8.16 presents the computation method processing directed versus directed measures. Figures 8.17a and 8.17b present directed and undirected j-graphs.

- ***Syntactic Analysis and Annotation of Linkography***

1| The process is distinguished for its rapid rate switching between too many sketching media. Three creative insights occur while shifting or extending the idea from one sketch to another.

2| As a rule of thumb, the increase in the undirected betweenness centrality is pertinent to the impact of the node on the following design actions constituting the imperative rule of that node bridging and transferring information from the precedents to the following medium sketch. The directed betweenness constitutes the rule of the node to its local network (to the precedents only).

3| The imposition of external constraint has split the local network with the precedents giving zero values for directed measures of integration and low closeness centrality.



4| Creative insights 16, 25, 41, and 63 deliver low integration values on balance to the other nodes in the whole system, constituting the deepness of the structure of their undirected networks. Further, directed integration is also delivering low-intermediate values for the same nodes, and thus their local networks are also structured deeply. From both measures; undirected and directed integration, we deduce that those insights are incremental dependent on the precedent actions, transferring information between different media as it is obviously reflected through the comparison between undirected and directed betweenness centrality measures.

Figure 8.16 Annotation of quantitative measures over linkograph – undirected versus directed measures (Case Study 2, Designer 2)

- ***Contrasting Directed and Undirected J-Graphs for Creative Insights***

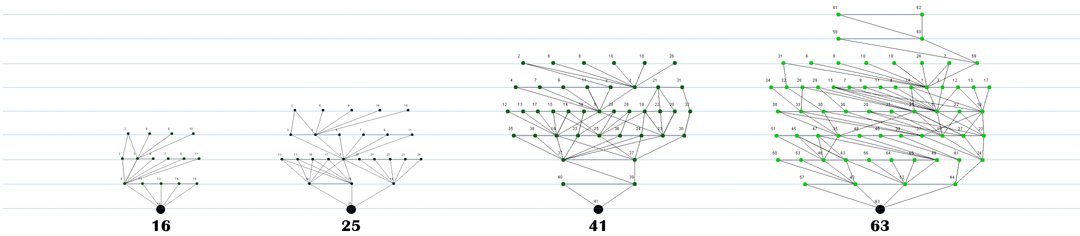


Figure 8.17a Creative insights represented by directed j-graphs for backlink relations (Case Study 2, Designer 2)

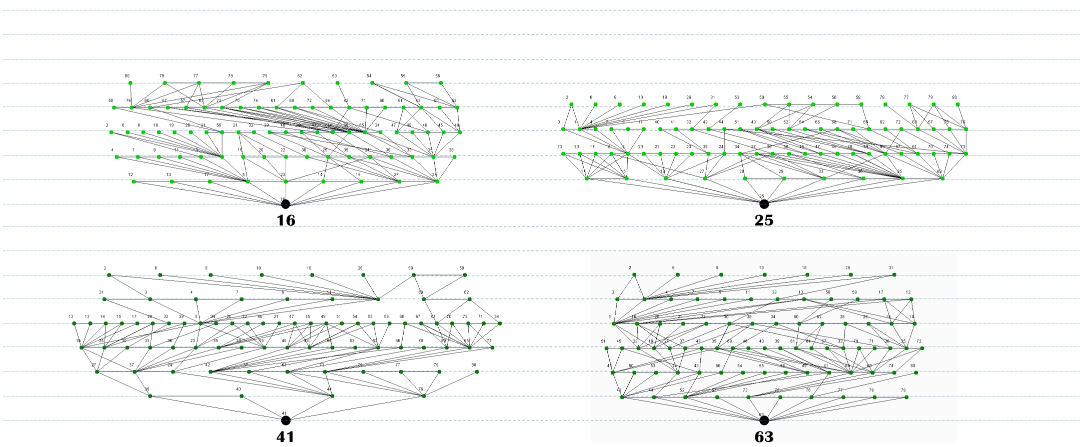


Figure 8.17b Creative insights represented by undirected j-graphs, concatenation of back and forelinks (Case Study 2, Designer 2)

- **Designer 3**

- ***Qualitative Description***

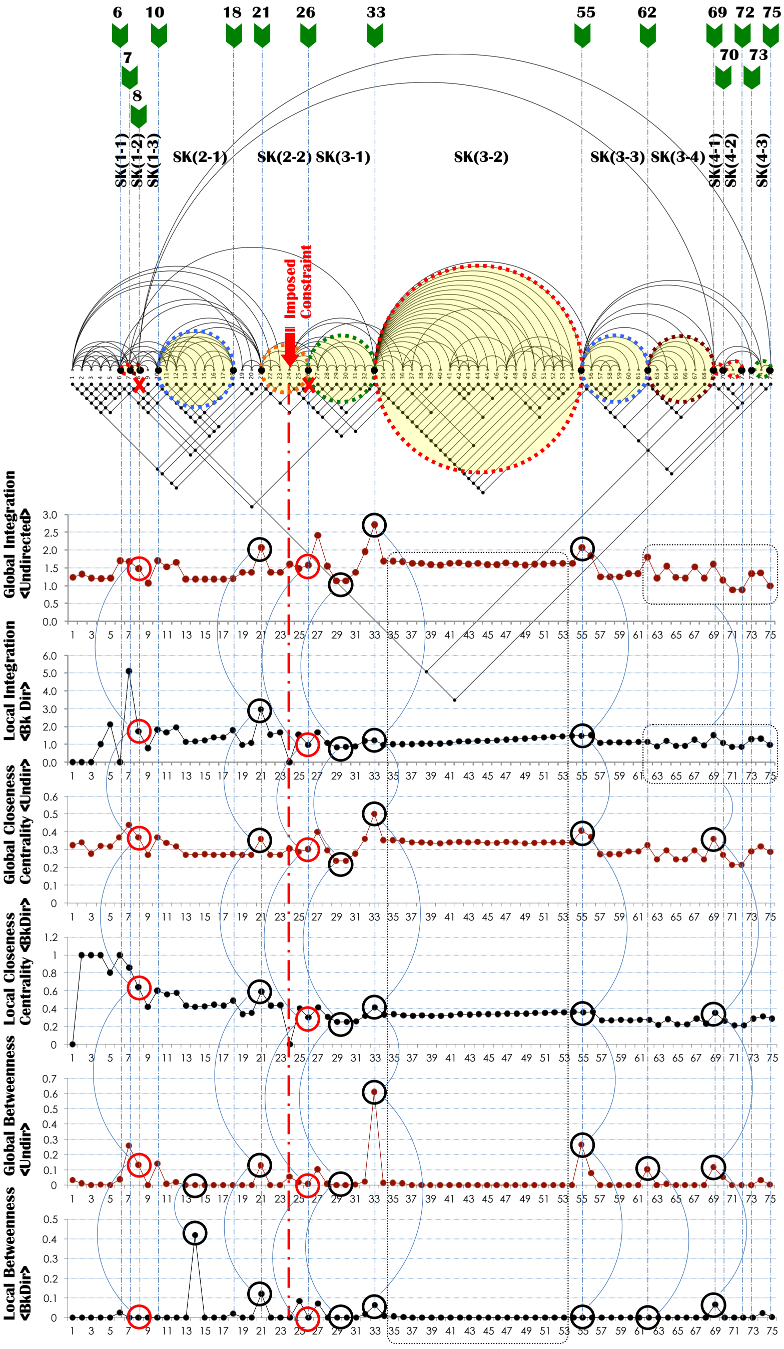
This design process is distinguished by the variation of its conceptual idea throughout the stages of designing. Two concepts were proposed in this process because of the imposition of an external constraint where one featured element in the former was removed in the amendments prior to the requested additional element. Specifically, a cylindrical form for the entrance was replaced by an orthogonal two-storey mass to include the showroom and entrance instead. Figure 8.18 presents the computation method processing directed versus directed measures. Figures 8.19a and 8.19b present directed and undirected j-graphs.

- ***Syntactic Analysis and Annotation of Linkography***

1| Creative actions at nodes 8 and 26 deliver median/low results for directed and undirected integration that reflect the median-deep of the network of relations created at each node.

2| Directed betweenness centrality delivered zero value for node 8 and 26. However, the undirected measure indicates an increase for node 8 reflecting a bridging role for the node transferring information to the following nodes, but delivered zero value for node 26.

3| Drastic change between directed and undirected betweenness centrality is also occurring at nodes 14, 33, 55, and 62.



4| Medium sketch SK(3-2) is distinguished for the balanced integration structure amongst the utterances from nodes 33 to 55 giving almost a horizontal undirected and directed integration. Nodes 33 and 55 are transitional, transferring knowledge between medium SK(3-1) to SK(3-2) and SK(3-2) to SK(3-3) respectively.

5| Final stages of the design process; media sketches SK(3-4), SK(4-1), SK(4-2) and SK(4-3), are entropic delivering wide range of integration values for both directed and undirected tools. For those nodes delivering low integration value, the structure of network is deep and vice versa for the high values, constituting for shallow structures.

Figure 8.18 Annotation of quantitative measures over linkograph – undirected versus directed measures (Case Study 2, Designer 3)

- ***Contrasting Directed and Undirected J-Graphs for Creative Insights***

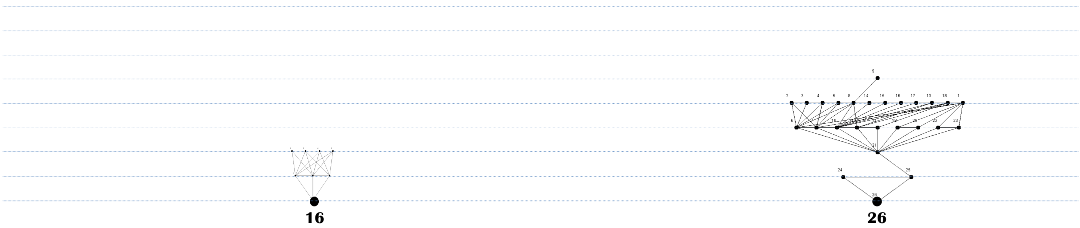


Figure 8.19a Creative insights represented by directed j-graphs for backlink relations (Case Study 2, Designer 3)

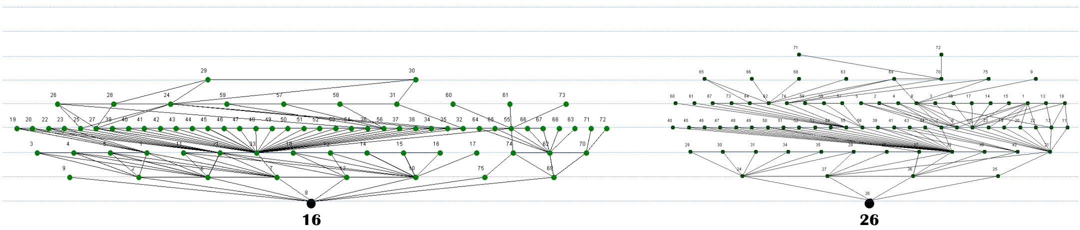


Figure 8.19b Creative insights represented by undirected j-graphs, concatenation of back and forelinks (Case Study 2, Designer 3)

8.5 Results and Discussion

This study presents a new method of looking at the design process. *Directed linkography* is a quantitative tool to detect the emergence of insights. By investigating venues where a *bridge* or *disconnection* occurs between different ideas, the impact of emergence on the overall structure is highlighted.

Two different situations are compared: *synchronous emergence* looks at *backlink* relations with preceding events (*local* measure), and the *diachronic* process of steps looks at *back* and *fore* relations after completion of the whole design process. This method describes the overall structure of design from *top-down* and from *bottom-up*. This study is developed from previous work modelling the design process where two quantitative methods are first applied to design linkographs: (1) *string t-code measures* look at a basic level of *direct* relations (El-Khouly and Penn, 2012a, 2012b); (2) *syntactic analysis* measures *depth* for each vertex estimating *direct* and *indirect* relations. This tool is better at capturing minor and major changes in the multilevel hierarchical structure. The proposed method is evaluated according to the following criteria:

8.5.1 A Proposed Framework for the Evaluation of Directed Linkograph

1. The ability to capture different states of design, modes of reasoning and types of creative insights.
2. Giving rise to the possibility of better understanding the conditions in which creativity and innovation take place, this method reveals the following effects:
   i. Incremental insights show *continuous reframing* of one former idea.
   ii. Sudden insights demonstrate *rapid restructuring* of the problem.
3. The accuracy of quantifying a multilevel graph is guaranteed using both *syntactic* and *t-code* measures, e.g. *depth* measure illustrates *disconnections* and *hierarchy*, *betweenness centrality* for *bridging* nodes, and *entropy* indicates *uncertainty* per node as well as *complexity*.
4. J-graphs describe the structure of the network for any insight at and after emergence.
5. The impact of significant events occurring is assumed to stimulate the formation of novel concepts, through investigating the relation between '*emergence*' and '*context of reasoning*'.
6. The following items are illustrated via directed linkography:
   i. Connectivity of vertices.
   ii. Integration of vertices with the structure of networks.
   iii. Multilevel identity for the network.
   iv. Capture of the sudden changes in the structure of reasoning and emergence of insights in the linkograph.

8.5.2 Multiple Configurations for the Impact of Emergence of Sudden Insights on the Structure of the Design Process

From a range of recorded observations, in different design situations, to describe the impact of sudden creative insights on the design process, the following configurations are derived:

- **Configuration of Bridging Nodes**

Bridging nodes transfer information from one idea to the next, which might cause collision between an old thought and the current situation. A creative solution may result from the sudden flash resulting from this unexpected collision. Figure 8.20 shows the following configurations that are outlined as contributing to structuring the design process:

1) **Configuration 'a':** represents a state where a design idea is initiated, developed and extensively improved. This chunk of thought is followed by a pertinent incremental insight occurring. The emergence has a relatively low effect on structuring the following process, especially where insights are integrated in the prevailing flow.
2) **Configuration 'b':** the creative insight could have a tremendous effect on the structure of the folowing process if it imposes a concept that is significantly reflected on the following actions and interim products. In this design situation, the insight acts as a *frame of reference* that continues until *hindrance* is experienced, requiring another insight to occur and exploration of another *frame* to overcome the problem experienced.
3) **Configuration 'c':** represents the emergence of insights, weakly connected with the preceding actions, but imposed on the flow, shifting the design to a new state. In this situation, the emergence shifts the design trajectory to a completely new paradigm, restructures the problem and redirects the concept to a significant lateral transformation. It imposes a specific structure on the upcoming events, tying the design concept to a new frame of reference.

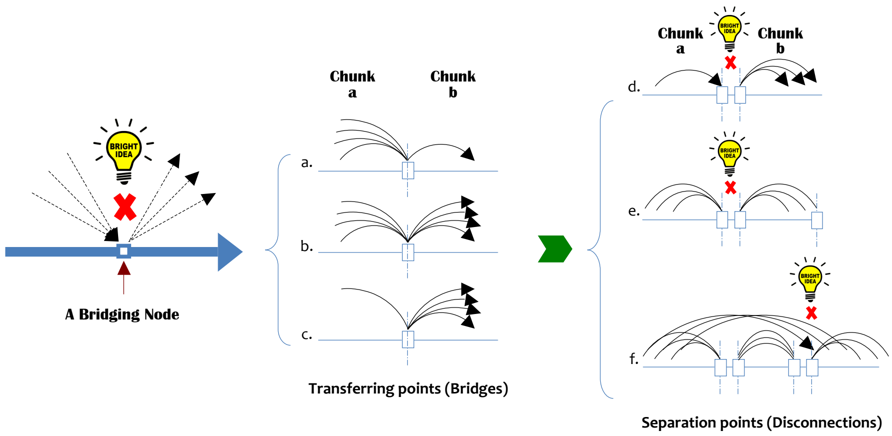


Figure 8.20 Multiple configurations for the impact of sudden insights on the structure of the design process

- **Configuration of Independent and Disconnected Events**

The emergence of sudden insights could result in shifting the flow to a completely different state. In this situation, the new paradigm radically shifts the process, leading to disconnection of the pattern of design synthesis. Two or more separate chunks appear in the linkograph, embracing *disconnection* nodes within its pivotal structure. Diagrams of different configurations are outlined in Figure 8.20 as follows:

4) **Configuration 'd'**: the disconnection separates the linkograph completely into two independent chunks of thought. In some states of design, the first stage might be hindering the process without providing inspiration to solve the problem, which a completely different idea could do.

5) **Configuration 'e'** presents two different situations. In spite of being sequential, both chunks of ideas are separate in their contents, developed independently. However each course of action may possibly nourish another idea that appears later or at the end of process.
6) **Configuration 'f'** shows a unique situation. The designer might diverge from a prevailing concept to explore a different one, gambling on another solution. A decision might then be taken to return to the old concept and develop it. This appears peculiar in the linkograph when a separate chunk appears in the pattern, while links are connected between *early* and *later* stages. A collision between old and present hunches might then occur following the decision to return to the old stream, giving rise to sudden insights.

8.5.3 Advantages of Directed Linkography

The advantages resulting from the directed linkography method are centred on the following points. First, the ability to distinguish different types of structures is associated with description of insights. The difference between sudden and incremental insights swings between deeply structured and shallow networks. According to the study sample, creative insights vary between both states. The more an insight appears to suddenly oppose the prevailing flow, the more the structure becomes shallow. This sudden change increases and in some cases causes a full disconnection.

Second, the characteristics of networks for sudden insights are considered shallow with 'few' or 'no' relations with the precedents. Incremental insights are significantly structured with backlink relations, dependent on the precedents, often represented by the deep structure.

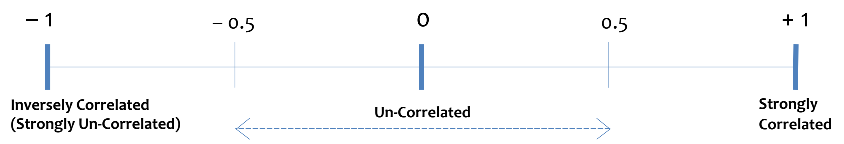
8.5.4 Relativisation

With our purpose of comparing design cases of linkographs of different sizes easily, syntactic attributes are considered normalised and ready for correlation. HH integration (Hillier and Hanson, 1984) is based on *relative asymmetry* (RA); a kind of integration that equals (*2MD-1/ K-2*) where 'MD' is the *mean depth* while 'k' stands for the *number of spaces* in the system (size). It was not available at the time to compare systems of different sizes. Nevertheless, 'D' value can be substituted automatically from Hillier and Hanson's pre-estimated empirical table in their influential book *The Social Logic of Space* (1984), giving an empirical integration value.

However, a *diamond* shape value was suggested to normalise the measures producing a new kind of integration called *real relative asymmetry* (RRA), which equals (*RA/D.k*), as 'D' value changes according to the size (*number of vertices*) in the system.[96] Hillier and Hanson developed integration into Integration HH, which equals: (*1/RRA*) where RRA was developed to normalise the integration measure. Since the syntactic measures are already normalised, RRA has paved the way to compare and correlate different size systems.

8.5.5 Correlation between *Directed* and *Undirected* Measures – Synchronic versus Diachronic Situations

According to our investigation, the *correlation coefficients* between *directed* and *undirected* measures are presented in the scatter graphs of Figures 8.21 and 8.22 and shown in Table 8.1 for each design experiment. The concept is that '*non-correlation*' reflects the change between directed and undirected measurements.



[96] 'D' is the value of diamond shape; the shape of the *justified* graph.

- **Design Case Study 1: Unstructured Brief – Expo Pavilion**

Reading Correlation Values for Designer 1

- Results are uncorrelated for integration reflecting the drastic change in the whole system being local compared to global.
- However, results are correlated for *closeness centrality* reflecting high correlation between how long it will take to spread information from a vertex to all other nodes sequentially in the local as well as the global states. As a rule of thumb, the more central a node is, the lower its total distance (depth) from all other nodes.
- Although a disconnected zone occurred in this design process and was placed within the network, it was treated separately as an isolated island. The main network is highly structured with no drastic changes captured in the structure from local to global levels.
- Vertices are either structured to the preceding actions or, conversely, linked forward to the following ones with few backlinks.
- *Betweenness centrality* measures are correlated. Nodes that act as a 'bridge' along the shortest path between two other nodes continue transferring information between chunks of thoughts from the local to the whole network. Conceptual ideas for those events are preserved along the process constituting the main pivots in the whole structure.

Reading Correlation Values for Designer 2

- Results show uncorrelated coefficients for the *integration* and *closeness centrality* values, reflecting instability of the system.
- *Betweenness centrality* measures are highly correlated, assuring a similar imperative role for those bridging nodes that maintained transferring knowledge between the preceding and following actions.
- The majority of nodes have imposed the structure after emergence when the characteristic of the pattern is significantly changed, which reflects the approach of *top-down* thinking process – particularly after the occurrence of sudden insights.

Reading Correlation Values for Designer 3

- The relations between undirected and directed measures are uncorrelated for integration and closeness centrality measures.
- *Betweenness centrality* measure is uncorrelated, which reflects the change in the role of bridging between nodes for both synchronous and diachronic situations of the emergence on the network. This non-correlation value signifies how different the imperative role is for the bridging nodes in this linkograph.
- The pattern of linkograph is highly structured and consistent with dense chunks of links that reflects an incremental accumulative design process – one conceptual idea prevailed in the flow but kept developing through until the end. However, the relation between the backlinks directed measure and concatenated links for the undirected measure for each node is significantly changing over the linkograph for each node, and thus delivering uncorrelated values for the three measurements.

- **Design Case Study 2: Structured Specified Brief – Cheese Factory**

Reading Correlation Values for Designer 1

- Directed and undirected results are uncorrelated for the three measurements.
- *Betweenness centrality* measures indicate the growing importance of some of the points on the network as a whole in order to link between chunks of thought and media of sketching; i.e. node 26 increased substantially from zero to 0.4.
- The pattern is insightful representing three major sketching media where two primary bridging points reside at transition between the three sub-networks.

Reading Correlation Values for Designer 2

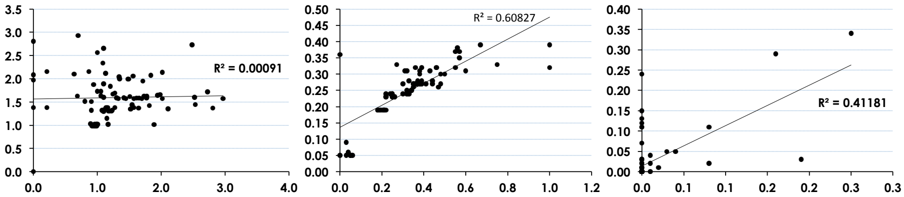
- Directed and undirected results for the integration and for closeness centrality measurements are uncorrelated.
- Directed and undirected betweenness centrality measures are correlated and deliver the coefficient 0.5.
- This is a structured process with long back/fore linking. Four insights occurred in the pattern delivering relatively deep backlinks structures.

Reading Correlation Values for Designer 3

- Directed and undirected of all measures are uncorrelated for integration, closeness centrality and betweenness.
- Although sudden insight occurred and restructured the design configuration, its imperative role remained in both synchronic and diachronic situations.
- The pattern is dense, highly compact, structured with chunks of links that constitute an incremental design process. Long 'back/fore' linkage is rare and ineffective in the overall structure.

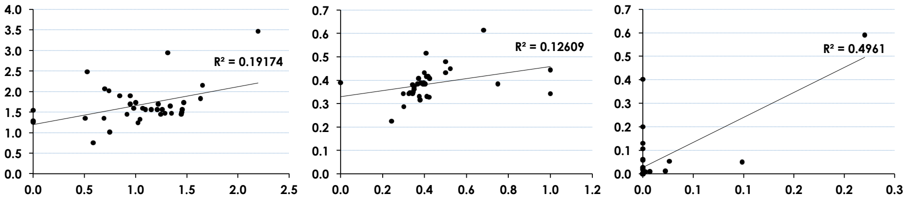
<u>Expo Pavilion</u>: <u>R^2 values reveal the relation between *directed* and *undirected* measures</u>:

<u>Subject 1</u>: **<dir> : <undir> Integration = 0.03**
<dir> : <undir> Closeness centrality = 0.78
<dir> : <undir> Betweenness centrality = 0.64
<dir> integration : <undir> Closeness centrality = 0.22
<undir> Integration : <undir> Closeness centrality = 0.53



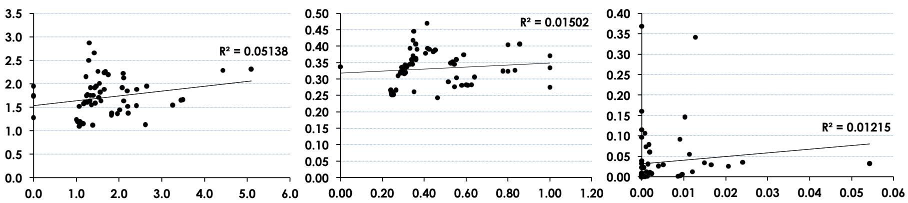
Dir int : Undir int   Dir CC : Undir CC   Dir BC : Undir BC

<u>Subject 2</u>: **<dir> : <undir> Integration = 0.44**
<dir> : <undir> Closeness centrality = 0.36
<dir> : <undir> Betweenness centrality = 0.7
<dir> integration : <undir> Closeness centrality = – 0.18
<undir> Integration : <undir> Closeness centrality = 0.93



Dir int : Undir int   Dir CC : Undir CC   Dir BC : Undir BC

<u>Subject 3</u>: **<dir> : <undir> Integration = 0.23**
<dir> : <undir> Closeness centrality = 0.12
<dir> : <undir> Betweenness centrality = 0.11
<dir> integration : <undir> Closeness centrality = – 0.81
<undir> Integration : <undir> Closeness centrality = – 0.99

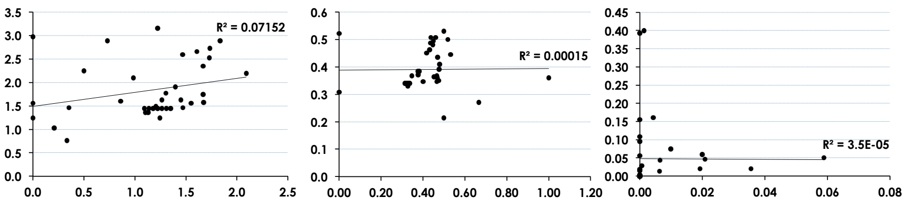


Dir int : Undir int   Dir CC : Undir CC   Dir BC : Undir BC

Figure 8.21 Correlation values between directed versus undirected for each measurement category – unstructured design cases

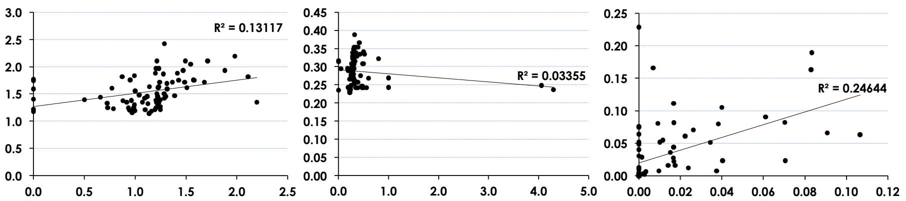
Case Study 2: R^2 values reveal the change between directed and undirected measures:

Subject 1: **<dir> : <undir> Integration = 0.27**
<dir> : <undir> Closeness centrality = 0.01
<dir> : <undir> Betweenness centrality = – 0.01
<dir> integration : <undir> Closeness centrality = 0.06
<undir> Integration : <undir> Closeness centrality = 0.98



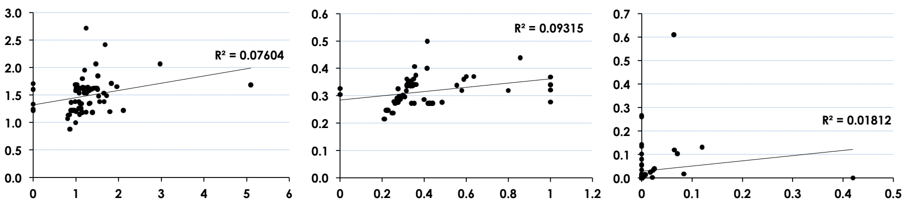
Dir int : Undir int Dir CC : Undir CC Dir BC : Undir BC

Subject 2: **<dir> : <undir> Integration = 0.1**
<dir> : <undir> Closeness centrality = – 0.18
<dir> : <undir> Betweenness centrality = 0.5
<dir> integration : <undir> Closeness centrality = 0.04
<undir> Integration : <undir> Closeness centrality = 0.99



Dir int : Undir int Dir CC : Undir CC Dir BC : Undir BC

Subject 3: **<dir> : <undir> Integration = 0.28**
<dir> : <undir> Closeness centrality = 0.31
<dir> : <undir> Betweenness centrality = 0.14
<dir> integration : <undir> Closeness centrality = – 0.25
<undir> Integration : <undir> Closeness centrality = – 0.87



Dir int : Undir int Dir CC : Undir CC Dir BC : Undir BC

Figure 8.22 Correlation values between directed versus undirected for each measurement category – structured/constrained design cases

Table 8.1 Correlation coefficients between *directed* and *undirected* measurements

	1st Measure	2nd Measure	R value	Relation
Design Case Study 1	**Unstructured Brief – Expo Pavilion**			
Designer 1	<dir> Integration	<undir> Integration	0.03	*Uncorrelated*
	<dir> Closeness centrality	<undir> Closeness centrality	0.78	*Strongly Correlated*
	<dir> Betweenness centrality	<undir> Betweenness centrality	0.64	*Strongly Correlated*
	<dir> Integration	<dir> Closeness centrality	0.22	*Uncorrelated*
	<undir> Integration	<undir> Closeness centrality	0.53	*Correlated*
Designer 2	<dir> Integration	<undir> Integration	0.44	*Uncorrelated*
	<dir> Closeness centrality	<undir> Closeness centrality	0.36	*Uncorrelated*
	<dir> Betweenness centrality	<undir> Betweenness centrality	0.7	*Strongly Correlated*
	<dir> Integration	<dir> Closeness centrality	– 0.18	*Uncorrelated*
	<undir> Integration	<undir> Closeness centrality	0.93	*Strongly Correlated*
Designer 3	<dir> Integration	<undir> Integration	0.23	*Uncorrelated*
	<dir> Closeness centrality	<undir> Closeness centrality	0.12	*Uncorrelated*
	<dir> Betweenness centrality	<undir> Betweenness centrality	0.11	*Uncorrelated*
	<dir> Integration	<dir> Closeness centrality	– 0.81	*Inversely Correlated*
	<undir> Integration	<undir> Closeness centrality	– 0.99	*Inversely Correlated*
Design Case Study 2	**Structured/Constrained Brief – Cheese Factory**			
Designer 1	<dir> Integration	<undir> Integration	0.27	*Uncorrelated*
	<dir> Closeness centrality	<undir> Closeness centrality	0.01	*Uncorrelated*
	<dir> Betweenness centrality	<undir> Betweenness centrality	– 0.01	*Uncorrelated*
	<dir> Integration	<dir> Closeness centrality	0.06	*Uncorrelated*
	<undir> Integration	<undir> Closeness centrality	0.98	*Strongly Correlated*
Designer 2	<dir> Integration	<undir> Integration	0.1	*Uncorrelated*
	<dir> Closeness centrality	<undir> Closeness centrality	– 0.18	*Uncorrelated*
	<dir> Betweenness centrality	<undir> Betweenness centrality	0.5	*Correlated*
	<dir> Integration	<dir> Closeness centrality	0.04	*Uncorrelated*
	<undir> Integration	<undir> Closeness centrality	– 0.99	*Inversely Correlated*
Designer 3	<dir> Integration	<undir> Integration	0.28	*Uncorrelated*
	<dir> Closeness centrality	<undir> Closeness centrality	0.31	*Uncorrelated*
	<dir> Betweenness centrality	<undir> Betweenness centrality	0.14	*Uncorrelated*
	<dir> Integration	<dir> Closeness centrality	0.25	*Uncorrelated*
	<undir> Integration	<undir> Closeness centrality	0.87	*Strongly Correlated*

8.5.6 Outcomes of Cross-Case Analyses

- In both cases (*Expo Pavilion* and *Cheese Factory*), the impact of sudden insights on the design process is represented using the comparative tool of directed linkography.
- Directed j-graphs for a spectrum of design insights reveal that both 'incremental' and 'sudden' insights have significant impact on the following actions and interim products.
- Creativity is structured in both cases. The emergence of apparently sudden insights, produced by the subconscious, enable the designer to structure the next steps according to the ideas transferred.[97]

[97] The story of Archimedes is a clear example of our reliance on *structured* creativity. He had realised the principle of floating

8.6 In Conclusion

Our aim of enquiring into design creativity and the formation of novel concepts, whether 'structured' or 'arbitrary', has revealed the need to develop an analytical tool that considers the dimension of 'time' to reveal the design process. This requisite is growing in the area of design research, in order to answer the question: '*how do sudden creative insights structure the design process*?' This can be investigated by processing the linkograph contrasting *directed* and *undirected* measures in correlation with descriptions of the contents and events taking place in the design process, such as verbal protocols, visual materials and any externalised artefacts. Linkographs are widely used in the area of design cognition research. The dependency relationships between design utterances can be examined throughout our proposed method of directed linkography. The relations are weighed by looking at the synchronous emergence of events and comparing the local network to the global structure for each design action after final completion. To reach a better understanding of the formation of novel concepts and design creativity, this quantitative method is proposed to detect the emergence of creative insights and in particular to capture any exceptional sudden changes to the prevailing order of the linkograph; assuming the influence of those insights on the evolution of good ideas and the formation of creative processes.

From the observation of many architects, it seems that *designing* processes basically rely on the *imposition of order on arbitrarily provoked ideas*. This kind of order could be seen as an internal cognitive structure imposed by the designer, or as a reflection resulting from the interaction with different material culture or artefacts, forms, objects, drawings or any types of external cognitive structures. Architects explore design ideas in a way that seems random but underlies *cognitive order*: thinking in two or three dimensions, sketching or scribbling, switching between different design media, building new syntheses, enriching the design process with good ideas and so forth. Most often the design process starts with an insightful phase where ideas about some conceptual elements are tossed around looking for one or more on which to base the concept.

Our derivation for this quantitative model is predominantly built on the actual characteristics of linkographs, considered as multilevel, hierarchical and pivotal structures. The measure of depth is being adopted to investigate the relations between ideas with the precedents of content with reference to time. The examples of applications showed exceptional states of design that varied from being completely disconnected from the course of design actions to conversely being highly structured on the prevailing flow. Our intention of examining this model is achieved in this chapter; however, the inclusion of more case studies in detail is required in future to unveil more configurations for the role of creative insights in the structure of reasoning.

8.7 Key Findings of Chapter 8

Directed linkography is useful for:

- Investigating the role of *design action* at the micro-level of *synchronous* relations and at the macro-level of *diachronic* relations; this contributes to detecting the extent to which the design products, creative cognition and design thinking are structured with the sudden occurrence of mental insights (see Finke et al. 1992; Ward et al., 1999); and investigating the role of sudden design *paradigm shifts* to re-steer and redirect the design helm and restructure the design configuration.
- Investigating a variety of design processes reveals two major types: (1) *hierarchical* – to achieve a predetermined goal; or (2) *transformational* – actions are interactively distributed and developed between the three aspects of the *distribution of cognition* of Hutchins' model (1995): (a) across *individuals* or *social group*, (b) through the coordination between *internal* and *external* cognitive structures (in the reflective practices between the designer's mind and interim design products), and (c) through *time* (earlier events may transform the nature of related events) (see Hutchins 1995).

bodies subconsciously. His Eureka insight structured his following actions into discovering that 'the displacement of water is equal to the volume of the floating shape', leading to the buoyancy principle. To discover whether the king's crown was of pure gold, he structured the following mathematical work accordingly: (1) he derived an equation to estimate the mass of the crown, and (2) he estimated density by dividing mass by the volume of water displaced, and concluded that the density was lower than that of pure gold proving that a cheaper and less dense metal had been substituted by the dishonest goldsmith.

Chapter

9 *Procedural* and *Contextual* Components in Design Reasoning and Creative Cognition:

Aspects of *Synthesis*, *Diversity* and *Originality* in the Empirical Study

This chapter looks at the design activities entailed in the empirical design case studies and draws conclusions on the synthesis processes and elements of diversity and originality in the final products of each case study. We will focus on the role of each of the chief elements – the spatial organisation of functional requirements, three-dimensional composition, and the circulation and distribution of functional spaces – which are hypothesised as significantly involved in the formation of the design concepts and configurations across the design stages. The chapter begins by considering the results of the empirical study of both experiments (the unstructured, open-ended design brief for the expo pavilion and the structured, specified and constrained problem of the cheese factory design) and then discusses the following features: (1) it identifies the context beyond the evolution of creative ideas; (2) it identifies the elements of diversity and originality; (3) it represents the grammar of synthesis in each case study and design process; (4) it identifies the cognitive style for each invitee architect; and (5) it illustrates the configuration of reasoning, incubation and evolution of creative insights in linkographs. In the end, this study aims to draw conclusions on the effect of procedural and contextual components in the process of reasoning, reflective practice and creative cognition.

The diversity of design products for the conducted empirical cases signifies the difference between the characteristics under investigation, e.g. the problem formulation, idea generation, and strategies through the reasoning process. The architects all showed competent but differing sketching skills to transform the mental imagery and spatial forms from one state to another.[98] *Reflective practice*, *sketching* and *imagery* are essential components in our proposition of the descriptive tool to understand the emergence of moves, evolution of ideas and formation of concepts by detecting the occurrence of creative actions, design eureka and aha moments. The configured networks of linkography reflect this variation of the characteristics due to the procedural and contextual components, back/forelinking, the interchange of information between products and so forth.

In this chapter, the similarities and differences of the cases are identified across data to draw conclusions on the procedural and contextual components in the design process. By identifying these aspects of synthesis across the cases, we aim to signify the effect of those components on forming the design approach and cognitive style of each designer. We aim to provide further proof of the reliability and validation of the proposed descriptive method from another perspective.

9.1 The Context Beyond the Evolution of Creative Ideas

In the *rational top-down* approach across the case studies, the early phase of concept initiation often presents one original idea that is probably dependent on the instructions provided in the design brief. The attempt to solve the design problem on this occasion relies on the functional programme. The architect who adopts a rational approach takes actions that decompose the main design problem into subsets and defines the configuration of design from the whole to the parts. Subsets of problems are related to the generic relation between the form and function; once defined, it is difficult to rearrange the matrix of relations for the overall configuration of form–function relation. In this way, the evolution of ideas probably results from the incremental reasoning of procedural components to execute predefined goals.

In the *non-rational bottom-up* approach across the case studies, a variety of conceptual elements (seeds of concepts) are designed and synthesised together to create the design configuration at the early phase of concept initiation. The *unexpected discovery* of ill-defined syntheses may result from trial-and-

[98] The variation in sketching skills relate to how they interpreted the resulting artefacts at each interim stage. The reflection-in-action, perceptions and gradual transformation of mental imagery differ from one architect to another: some relied on one sequence sketching while others kept changing the flow from one idea to another to generate as many ideas as they could. As stated earlier in the thesis, discontinuity while sketching is a drive for creative thinking: the unexpected discovery is dependent on the architect's rational or non-rational reasoning, reflected through the way they sketch and transform ideas from one stage to another.

error attempts leading to critical moves occurring. On this specific occasion, the occurrence of unexpected creative insights may lead to redefining the set of goals; reformulating the whole configuration in the extreme case leading to a breaking point to restructure the design problem and explore the design space to generate the best solution.

In one possible approach to form a 'good' concept, the designer may resynthesise the conceptual elements differently to come up with unexpected combinations. Shuffling and reshuffling the matrix of relations between the functional elements and morphology of forms could lead to the occurrence of sudden creative insights. This event was identified in Chiang's study (2006), transforming the landscape of the design problem after experiencing fixation effect (called 'bottleneck') to facilitate the generation of solutions:

> Design eureka functions more likely as an effective act of changing the problem landscape into become more plausible for forming solutions, rather than as an effective solution per se. In this light, 'changing-problems' instead of 'solving-problems' holds the key to the design eureka (Chiang, 2006: 2).

The process of generating exceptional and creative ideas is linked to understanding the context of the design situation under development, attempting to build on it; such as introducing modern vocabulary elements or innovative concepts for functional or morphological features, or synthesising prototypes of solutions for such building type. The designer develops the design in progress by trying to generate ideas for creative solutions, which may lead to reliance on 'procedural' or 'contextual' solutions according to the objectives of this stage. In conclusion, sudden mental insights are likely to occur in a non-rational reasoning process of creative discovery based on the unexpected syntheses.

In this study, the components of similarity and difference across the case studies are surveyed to introduce a comprehensive overview of the outcomes and activities of work (see Table 9.1 and Figure 9.1). Tables 9.2 and 9.3 illuminate the context beyond the emergence of critical actions and creative insights in each set of design cases. This is a synopsis to provide an overview of the collected data from which to draw conclusions in this chapter.

Table 9.1 Description of design activities across the design cases

	Unstructured, Open-ended, Design Case Study 1 ***Expo Pavilion***						**Structured, Specified (Constrained) Design Case Study 2:** ***Cheese Factory***					
Survey across design experiments	**Designer 1**		**Designer 2**		**Designer 3**		**Designer 1**		**Designer 2**		**Designer 3**	
Design actions (utterances) – vertices per linkograph	**86**		**36**		**62**		**37**		**80**		**75**	
Interim products per design process	#	%	#	%	#	%	#	%	#	%	#	%
	26	30.2	**11**	30.5	**6**	9.7	**12**	32.4	**33**	41.3	**11**	14.7
Steps/actions of drawing episodes	**83**	96.5	**31**	86.1	**44**	71	**25**	67.5	**64**	80	**30**	40
Identified critical actions (including creative insights)	**23**	26.7	**8**	22.2	**2**	3.22	**4**	10.8	**4**	5	**3**	4
Eye glances back on the design brief while designing	**3**	3.5	**3**	8.3	**1**	1.6	**3**	8.1	**10**	12.5	**3**	4
Concurrent comments (during or in between designing actions)	**0**	–	**7**	19.4	**44**	71	**2**	5.4	**4**	5	**37**	49.3
Thinking pauses	**3**	3.5	**14**	38.9	**1**	1.6	**2**	5.4	**13**	16.3	**7**	9.3
Switching between sketching media	**30**	34.9	**16**	44.4	**7**	11.3	**20**	54.1	**55**	68.8	**11**	14.7
Rate of switching media (*switch per minute*)	0.5 sw/min		0.27 sw/min		0.11 sw/min		0.54 sw/min		0.68 sw/min		0.15 sw/min	

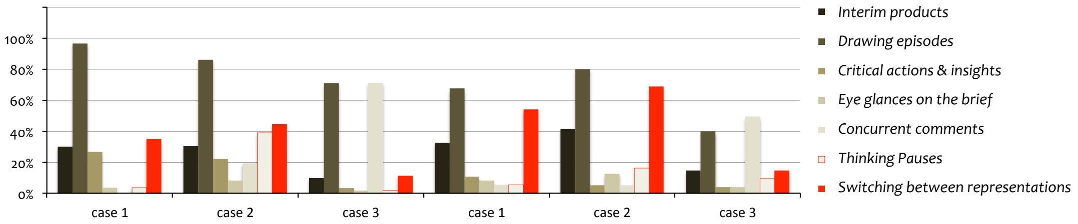


Figure 9.1 Description of the outcomes and design activities across the design cases

Table 9.2 Description of the context behind the emergence of creative insights across unstructured Case Study 1, Designers 1–3

Unstructured, Unspecified, Open-ended Design Case Study 1 (Expo Pavilion)			
Index of critical creative actions	**Description of the context behind the emergent insight**	**Relations with interim products**	**Transformation in the design process**
Designer 1			
2:8, 11 and 15	Sketching episodes presented a variety of independent conceptual elements that were deployed to build syntheses of concepts all through the design process	Media switches and exchange of information between the representations created forms of reflections-in-action and led to independent sketching episodes at some stages of design	This design process adopted an inductive explorative approach to initiate the concept. Elements were synthesised to create a variety of solutions for the pavilion in the following phases, but a fully disconnected zone represented a totally independent and unprecedented concept in the entire process that restructured the design configuration and produced an independent pavilion. At the end of the process, another solution for the pavilion emerged that was dependent on the initial set of concepts. This process reflects insightful thinking at the early beginning
17, 18, and 19	Initiating conceptual idea different from the former concept based on building synthesis with earlier thoughts	Developing the idea and exchanging it through different projections; entire switch preserving the original concept	
24	Sketching to generate new conceptual element, adding it to the first set of concept initiation	Updating the list of concept elements with a new feature that emerged while designing the first pavilion	
26, 27, and 31	Initiating a concept that was different from the prevailing concept based on creating synthesis with the set of conceptual elements at initiation	At this stage, the concept was developed based on the initial set and it was transformed through different projections (plan, section, perspective)	
52	Sketching back to the mind, a new conceptual element updated the initial set of concepts	Perception-in-action with the artefact occurred to generate new form of imagery in the mind	
60 and 70	Initiating the concept at this phase was semi-dependent on the initial set and referred to the preceding actions	A novel solution emerged: design configuration embedded the concept of lighting that considered the initial set, but a novel architectural treatment was designed for this product	
71	Initiating a novel concept independent from the prevalent flow and unprecedented in the whole design process – it had no reference to any of the preceding actions	At this action, eureka sudden insight occurred in the process, restructured the situation and provided an independent solution	
82	Initiating this concept relied on retrieving an element from the initial set	The concept was developed through different projections (perspective and section)	
Designer 2			
2, 6, 8, 9, 11 and 14	A variety of sketching episodes that presented independent elements to initiate the concept. This initial set diversified the products, provided a several proposals of solution and was deployed to create syntheses all through the design process	Concepts were synthesised to create a congregated layout for the design configuration	The initiation phase process adopted an explorative approach to generate variant solutions for the design problem, which were synthesised and developed throughout convergent process. It reflects insightful thinking at the early beginning of the design process
16 and 25	These actions presented convergent thinking; the initial set of elements were combined into one congregated configuration of the concept	Actions of convergence generated one product	
Designer 3			
14	Sudden mental insight occurred while designing the site-layout, which outlined the form of cross-section	This sudden emergent concept was adopted to develop the initial concept	This design process adopted a rational approach and started with one concept that was developed and transformed all through the process
51	Restructuring the design configuration and rearranging the relations between the functional spaces due to the imposition of external constraint	This interim product was redesigned after the imposition of the new request in a way that some functional spaces were flipped, mirrored and modified to include the new functional requirements	

Table 9.3 Description of the context behind the emergence of creative insights across unstructured Case Study 2, Designers 1–3

Structured, Specified, Constrained Design Case Study (Cheese Factory)			
Index of critical creative actions	**Description of the context behind the emergent insight**	**Relations with interim products**	**Transformation in the design process**
Designer 1			
10	Framing the concept of three split elongated forms each of which occupied a certain function. This initial concept prevailed until the end of the process but with slight modifications	This sketch SK(3-1) was designed on the instructions of the design brief and transformed the functional programme into zoning diagram	The design process adopted an explorative approach to design conceptual elements of the project during the initiation phase that were inspired by the design brief's instruction and functional programme. Conceptual elements were used to create models of syntheses that provide various possible ideas to solve the required functional programme and overcome any imposed constraint throughout the design process
14	Framing the concept of spatial configuration; creating triple height space for the manufacturing hall; locating the offices in a split mezzanine; and utilities. This initial concept was recalled and synthesised through the process with slight modifications	This sketch SK(1-4) presented an architectural treatment for the cross-section that transformed imagery into spatial form. It was unprecedented at this stage in the design process and reflected the architect's view of the distribution of functions between the three split forms	
26	Framing the decision to displace the elongated forms and create outdoors courts. This concept was transformed after the imposition of external constraint and outdoors courts were omitted	This sketch SK(2-5) presented a stage of transformation on the original concept. It was initiated from the preceding form with slight modifications to consider the reflections with the design scenario	
35	This was a creative insight to solve the problem by creating an overlap in the third dimension between the elongated forms	This diagram SK(3-1) was a new treatment for the elongated forms by creating overlapping/intersecting areas	
Designer 2			
16	Framing the concept of looped circulation to link between two vertically split floors; utilities at the ground floor and manufacturing at the first floor	This sketch SK(2-2) was developed from the preceding interim product for the first proposal of design. It supported the initial concept to separate the main functions between different floors	This process generated several proposals for the concept and pertinent architectural treatments all through the process. Synthesis between those proposals helped to ground the solution and create convergence model during some stages, allowing sudden solutions to occur. Imposition of sudden insight created disruptive event but perseverance was shown to reframe the original solution and modify it slightly to accommodate the new requirement
25	Framing the concept of zigzag route and arrangement of functional equipment of the manufacturing line	This idea SK(3-1) was unprecedented at this stage of the design process and solved the problem of distributing the production line equipment. However, it was initiated from the incremental development of the preceding artefacts of master plans	
41	A metaphor to design the outer skin of façades –sliced metal cladding	This architectural treatment of sketch SK(4-8) was unprecedented at this stage of the design process. However, it reflected a direct analogy of the design brief	
63	Reframing the original solution with an extended mass to accommodate the requested exhibition hall	This sketch SK(5-6) reframed the original concept while attempting to solve the external condition and include the exhibition hall within the form composition, creating an extension that was exposed over four pillars	
Designer 3			
8	This was a creative leap, sketching a 3-D perspective from the mental imagery	This model was sketched on the zoning diagram without sketching the 2-D master plan	This process showed adherence to one concept all through the process. It adopted an incremental structured approach to designing the project. The design configuration was entirely restructured after the imposition of external constraint while fixation was experienced. The final outcomes reflected remarkable modification on the design configuration and 3-D composition
26	This was a sudden insight to restructure the design configuration; flipping the master plan after the imposition of external constraint	Flipping the original master plan all around to redefine the spatial configuration and relations between the functional spaces. The new plan was designed tracing over the flipped design. Drastic modifications were made, e.g. omitting the cylinder from the spatial composition	

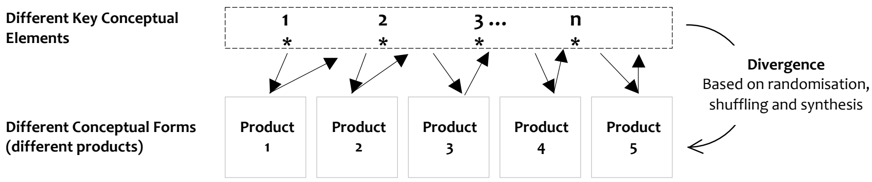
9.2 Models of *Synthesis* and *Creativity*: *Diversity* and *Originality* in the case studies

This section sheds light on the aspects of *synthesis* and *creativity* that have formulated and structured the design concept in each design case. The variety of conceptual elements that formulated the synthesis process between the stages of design switched the cognitive representations between the mental imagery and the interim artefacts. Our central focus is on investigating the relation between the early phase of *concept initiation* and the following stages. This study aims to outline the configurations of synthesis that the creative process may take in similar case studies.

9.2.1 Case Study 1 Unstructured Brief – Expo Pavilion

- **Designer 1**

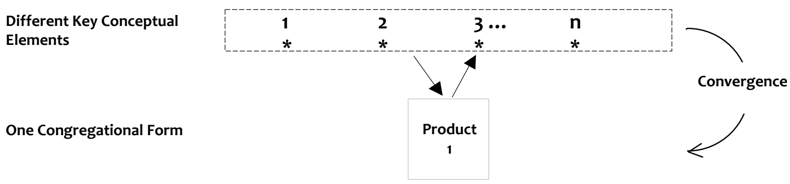
- **Early phase of initiation**: a variety of conceptual elements are outlined.
- **Designing phases**: five different conceptual forms, where each form was developed through operational and finalisation stages.



- **Model 1: Divergence model based on building synthesis between different conceptual elements** is achieved through:
  - *Bottom-up process:* initiating the concept is based on independent units of conceptual elements and building synthesis
  - *Randomisation and shuffling elements:* creating high variation and diversity between concepts of the final products
  - *Proposals are developed based on high uncertainty* (uncertainty is the motivation for exploration and creativity).

- **Designer 2**

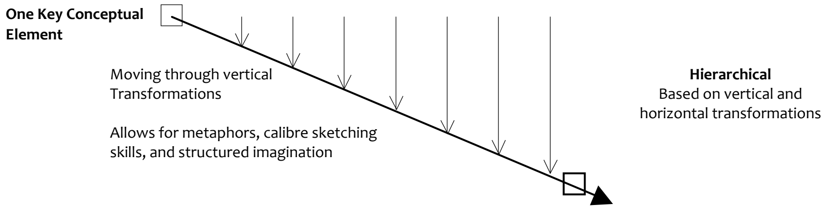
- **Early phase of initiation**: different conceptual elements.
- **Designing phases**: one prime conceptual form, followed by operational and finalisation stages.



- **Model 2: Convergence model** is achieved through:
  - *Design process:* initiating the concept is based on independent concepts and creating convergence into one conceptual form
  - *Convergence* into one framed design problem
  - *Proposal is developed with less uncertainty*.

- **Designer 3**

- **Early phase of initiation** is dependent on 'metaphor'.
- **Designing phases:** one prime conceptual form is followed by operational (execution) and finalisation stages.

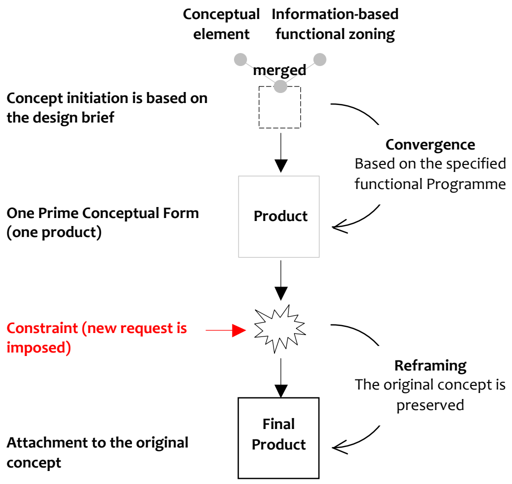


- **Model 3: Discursive transformational model** is achieved through:
  - *Top-down process:* initiating the concept is based on one primary conceptual idea that is achieved through a series of incremental actions
  - *Convergence:* attachment to the initial concept and one framed design problem
  - *Proposal is developed with less uncertainty*.

9.2.2 Case Study 2 Structured Specified Brief – Cheese Factory

- **Designer 1**

- **Early phase of initiation**: the 'zoning' functional programme is based on the design brief (information-based zoning diagram to represent the functional requirements).
- **Designing phases**: one prime conceptual form is followed by operational (execution) and finalisation stages.

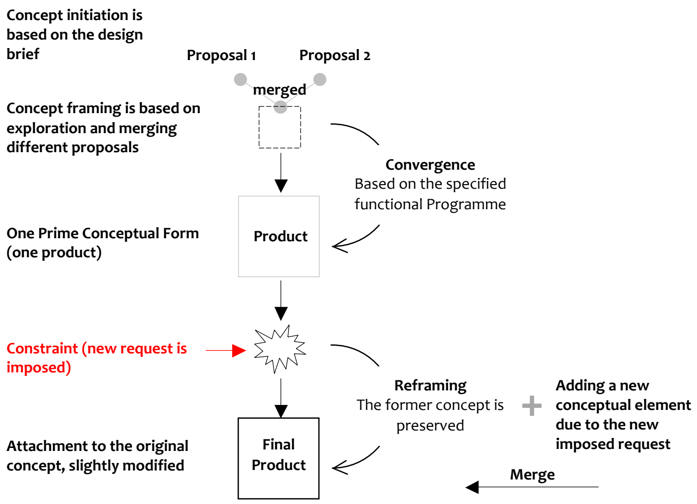


- With the aim of preserving the original concept (attachment status), finding conceptual alternatives for the form composition depends on the architect's personal skills of sketching. Creative process is more dependent on the quality of the subject's skills of designing, imagination and sketching.
- The more rigid the design (limited configuration, facing stagnation, highly constrained functional programme, the idea of sterile etc.), the more intervention relies on personal skills (idiosyncrasies).

- **Model 4: Convergence model** is achieved through:
  - *Design process:* designing a generic form (an envelope for the design) and building synthesis between conceptual elements
  - *Convergence:* attachment to the initial form. Iterations to elaborate diversity to create different conceptual forms/proposals are effective in overcoming the constraint imposed by the new request
  - *Imposed constraint:* leading to reframing the original concept
  - *Proposal is developed with uncertainty*.

- **Designer 2**

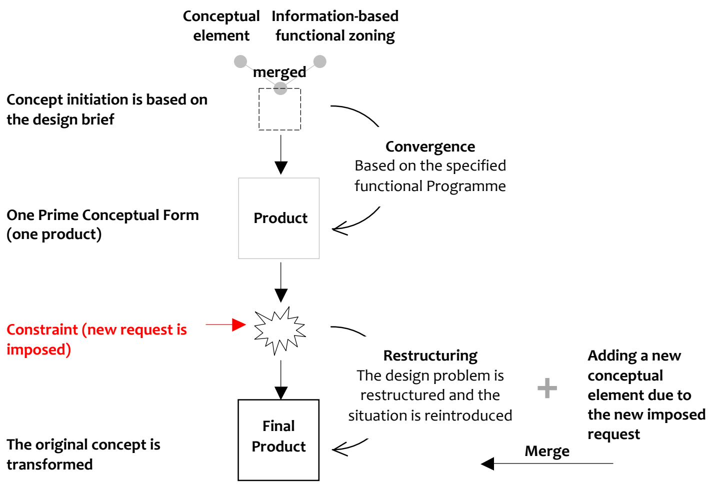
  - **Early phase of initiation**: information-based zoning plans based on the functional requirements included in the design brief – diversity is achieved through exploring different alternatives at this phase.
  - **Designing phases**: one prime conceptual form is followed by operational and finalisation stages.



- **Model 5: Convergence model. Reframing the initial solution is structured and dependent on synthesis** is achieved through:
  - *Top-down process:* perseverance of the original concept with diversity is based on exploring various proposals at the initiation phase
  - *Convergence:* attachment to the initial concept of one framed design problem. Iterations to elaborate diversity to create different conceptual forms/proposal are less effective than the case of unstructured/unspecified brief
  - *Imposed constraint:* leading to reframing the original concept and adding a new conceptual element merging it to the original design
  - *Product is developed with high uncertainty*.

- **Designer 3**

- **Early phase of initiation**: information-based zoning diagrams based on the functional requirements included in the design brief.
- **Designing phases**: one prime conceptual form, followed by operational and finalisation stages adopting personal skills and idiosyncrasies until the imposition of new request, then the whole structure of the design problem is reintroduced (top-down, bottom-up processes).



- **Model 6: Divergence model. Restructuring the whole design problem, reintroducing the design situation,** is achieved through:
  - *Top-down/bottom-up process:* setting the basic structure of the concept and going through details, once a problem is framed (such as the imposed constraint to add a new functional space), the solution is initiated by solving the requested problem's details and move up to reset the final concept accordingly. Diversity is an outcome of this divergent redirectional model
  - *Divergence:* breaking out of the former frame of reference, shifting to a different one
  - *Imposed constraint:* leading to restructuring the original concept but introducing the design situation and adding a new conceptual element
  - *Product is developed with high uncertainty*.

9.3 Grammatical Representation of the Conceptual Elements in the Synthesis Process

This section illuminates the main conceptual elements and provides grammatical models of synthesis between those elements, which contributed in the formation of design concept in each case study. Three primary aspects are nominated for the criterion of conceptual configuration in this investigation: *spatial configuration*, *synthesis of three-dimensional form*, and *circulation and distribution of functional elements*. We adopt a qualitative approach to interpret the synthesis process between these three aspects, which is built on our ethnographic observations and on the architects' comments during and after the design process in each case. This study takes into consideration any generated design option, proposal or solution alternative that could play vital or subsidiary roles in the synthesis process and/or the final design configuration.

The synthesis process is central and relevant to the context of our investigation because it reflects the causes of *diversity* and *originality* in the design process, which are considered key sources for creative ideas to emerge. This study hypothesises that the emergence of creative ideas according to synthesis contributes significantly to restructuring the reasoning process of the subsequent actions while some critical actions and products act as *creative hinges* in this development. This study also examines the proposition that design is likely to be a top-down process, following Hillier's model (1998) that the 'form–function' relation cannot be dealt with fully other than by having a notion at the level of the whole configuration, spatial design is likely to be a 'top-down' process, and a solution cannot be evolved 'bottom-up' from the parts.

> how the parts fit together is the critical factor, and the addition of a new part at any stage may change the structural characteristics of the whole. The form-function relation is emergent at the top level (Hillier, 1998: 40).

In this study, we investigate whether a *hierarchical* design process is implied when the form–function relation is configured at the global level of reasoning structure, and whether the design actions are mainly attempts to solve this relation and its predefined goals.

Our intention in investigating the context beyond the occurrence of sudden insights in the synthesis process is to examine how the form–function relation may be restructured accordingly. It is quite crucial to explain the role of the design brief on the synthesis process and reveal the context that supports, or hinders, the synthesis process; revealing the aspects of synthesis in the free unstructured, unrestricted and in the highly specified restricted functional programme.

One of the most critical points for this analysis is to characterise the structure of reasoning and development of concepts through the design process and to reveal factors that might have an impact on the synthesis process and emergence of unexpected creative insights. The following taxonomy outlines our investigation. It explains the development of each conceptual aspect in the design process, *diversity* and *originality* of outcomes in the operational/developmental and final phases, whether novel elements are introduced to the design discourse or mere crossbreeding between initial proposals takes place without the intrusion of new conceptual elements.

9.3.1 Case Study 1: Unstructured Brief

- Designer 1

The major elements and derivatives are coded into grammatical symbols and the syntheses are represented for each product in every designing stage (see Figure 9.2). The following points outline the synthesis process:

- ***Synthesis Process for Each Design Element***

Spatial organisation of functional requirements:

- Three types of spatial organisation were proposed in the initiation phase to build the concept on: *central*, *linear* and *complex* organisation. The central type (A_1) was utilised to develop pavilions 4 and 5; the linear type (B_1) was deployed to develop pavilions pavilion 3; and the complex type (C_1) was adopted as setup for pavilions 1 and 2.
- The operational process of development for those pavilions kept each organisation type as it was without further synthesis or crossbreeding with other spatial elements.

Three-dimensional composition:

- Three types for the synthesis of the 3-D form were proposed in the initiation phase: *irrational*, *central* and *linear* forms. The irrational type (A_2) was utilised to develop pavilion 1, the central type (B_2) was deployed to develop pavilions pavilion 2, 4 and 5, and the linear (C_2) type was adopted as setup for pavilions 3.
- The operational process of development for those pavilions kept each type as it was without further synthesis or crossbreeding with the other types.

Circulation and distribution of functional spaces:

- Two circulation types to distribute the functional spaces in the master plan were proposed in the initiation phase: *central* and *linear*. The central type of circulation (A_3) was implemented to develop pavilions 1, 2, 4 and 5, while the linear type (B_3) was deployed for the proposition of pavilion 3.
- The operational process of development for those pavilions kept each type as it was without further synthesis or crossbreeding with the other types.

- ***Diversity and Originality***

- Variety of synthesis in the concept initiation was according to the numerous conceptual elements and proposals that provided free rein in the process to synthesise and create multiple design alternatives. However, the operational and developmental phase reflected convergence to develop each element in recursive and discursive ways, undermining the possibility for crossbreeding with other elements to foster novelty.

- ***Design Process Approach***

- This was a bottom-up process where key conceptual elements were designed at first hand then synthesised to form the conceptual idea for each product pavilion.
- Sudden insights occurred during the synthesis process where results were unexpectedly discovered.

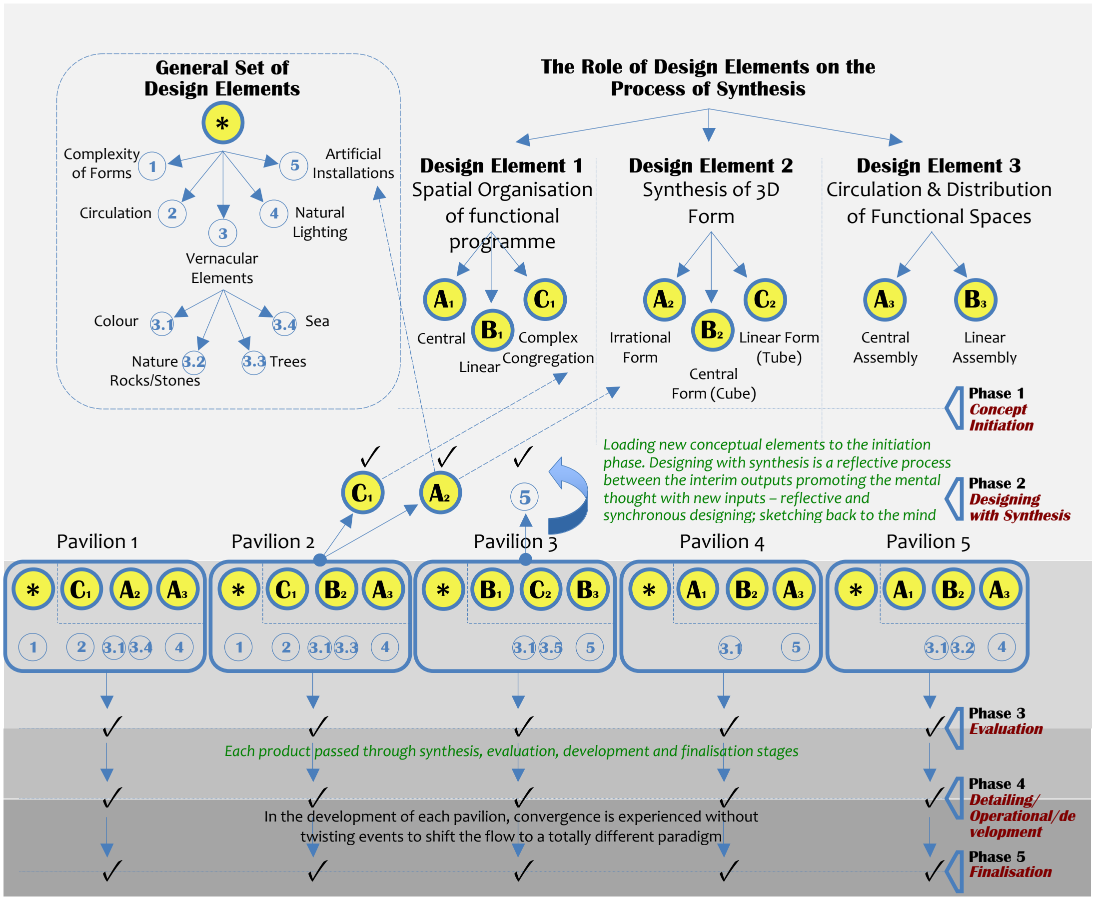


Figure 9.2 Grammars of the synthesis process (Case Study 1, Design 1)

- **Designer 2**

Figure 9.3 illustrates the primary and derivative elements that were deployed for the synthesis process and design of the interim artefacts. The following points outline the synthesis process:

- ***Synthesis Process for Each Design Element***

Spatial organisation of functional requirements:

- Two types of spatial organisation were proposed in the process: the *central spatial* type (A_1) was proposed for most of the conceptual elements in the initiation phase while the *complex* organisation type (B_1) was proposed for a few elements in addition to the congregated site plan where all the proposed ideas for pavilions were collected and linked in one congregated complex site in the development/operational phase.

- Central and complex spatial types were synthesised in the convergence-based phase. All conceptual pavilions were combined in one conceptual site-plan. This was followed by an improvisation and finalisation phase.

Three-dimensional composition:

- Three types for synthesis in the 3-D form were proposed in the initiation phase: *central*, *organic* and *complex* forms. The central type (A_2) was utilised to develop conceptual idea of the empty box and the roulette wheel, the organic type (B_2) was deployed to develop the entertainment idea of village life, and the complex type (C_2) was used to design the science pavilion, the user-generated disorder pavilion, and congregational site plan.

Circulation and distribution of functional spaces:

- The circulation and distribution of the functional spaces took two types: *central* and *complex*. The central assembly (A_3) appeared for the conceptual elements in the concept initiation phase, and the complex assembly (B_3) appeared for the design of the congregational site plan.

- ***Diversity and Originality***

- The early phase of concept initiation is distinguished by the variety of conceptual elements and proposals that provided free rein in the process to synthesise and create multiple design alternatives that the concept hinged on. However, the following phase of development reflected some convergence with an aim to design one congregated site-plan of all the individual elements but based on one particular element that centred the design in a magnified scale, surrounded by the other elements. At this phase, the possibility for crossbreeding between elements was undermined by the convergence state, which reduced the originality and novelty of the stage on balance to the earlier concept initiation.

- ***Design Process Approach***

- This is a bottom-up process; primary conceptual elements were designed then synthesised to form the conceptual idea for each product pavilion.
- Sudden insights occurred during the radical shifts between each concept element and the following at the concept initiation phase where results were unexpectedly discovered; however, insights turned out later to be incremental based on the developmental process.

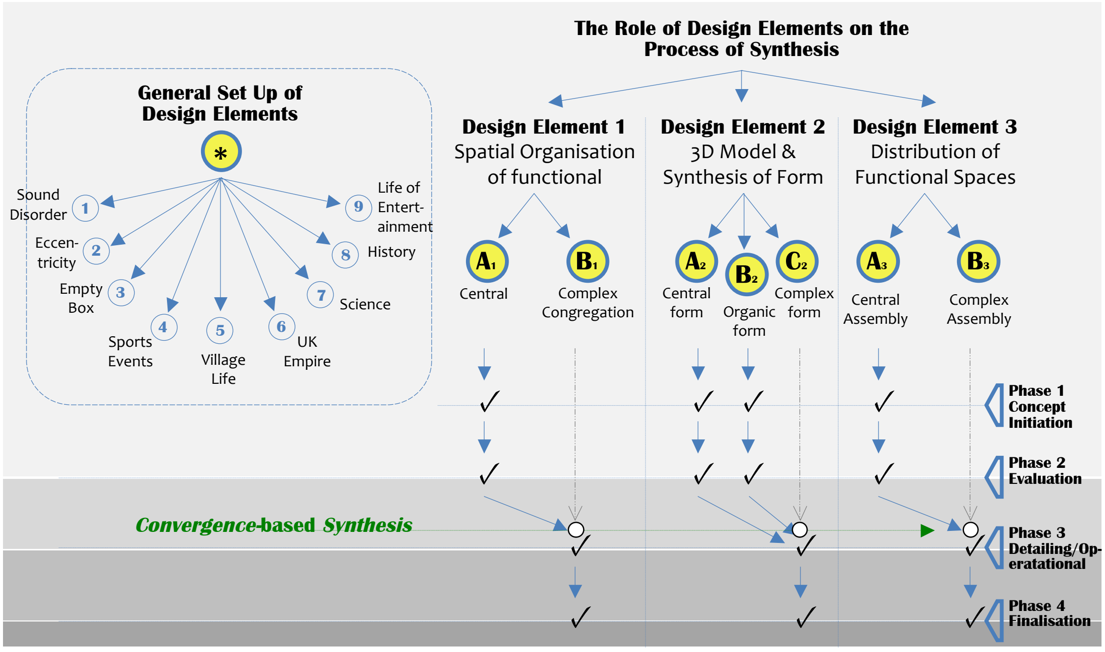


Figure 9.3 Grammars of the synthesis process (Case Study 1, Designer 2)

- **Designer 3**

Figure 9.4 illustrates the primary and derivative elements that were deployed for the synthesis process and design of the interim artefacts. The following points outline the synthesis process:

- ***Synthesis Process for Each Design Element***

Spatial organisation of functional requirements:

- One concept was proposed in the initiation process for spatial organisation. *Complex* organisation (A_1) was based on proposing a composition of different random masses expressing the conceptual idea. This spatial type was preserved for the design composition until the end of the process.
- The following stages of design and subsequent operational activities were recursively initiated based on type (A_1), discursively developed, but no synthesis or crossbreeding with any other types was monitored.

Three-dimensional composition:

- One type was proposed for the 3-D form; complex composition of interlocking overlapping forms (A_2) was developed based on the spatial organisation (A_1) representing the designer's vision of philosophical concept.

Circulation and distribution of functional spaces:

- The circulation type for this composition and distribution of functional spaces took the form of *linear* assembly (A_3) for a one-way route considering the complex spatial configuration of spaces.

- ***Diversity and Originality***

- Diversity and originality are assessed by judging the composition as a whole not based on individual conceptual elements. Creative leaps of sketching shifted the design process from a state to another reflecting high calibre of imagination compared to the regular modes of sketching in this process.

- ***Design Process Approach***

- This is a top-down process, primarily started with one major conceptual design idea, then decomposed into minor elements covering several aspects of problem solving. Incremental insights occurred during the transformation of the idea from one stage of development to another.

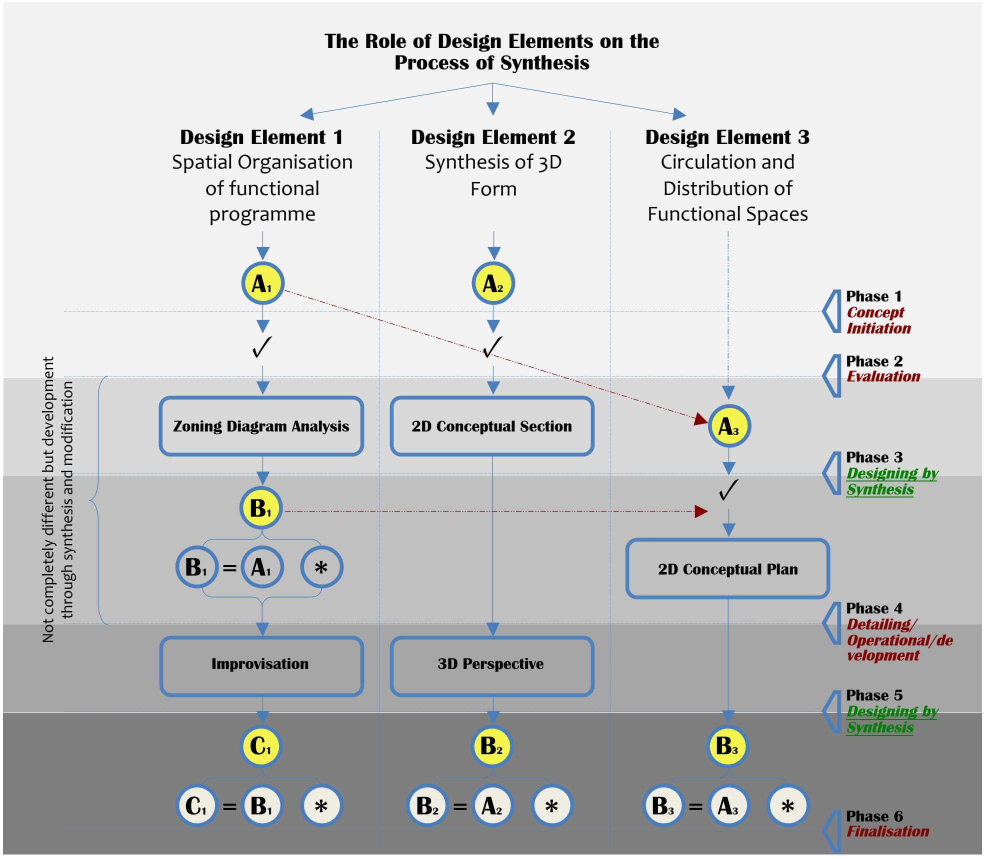


Figure 9.4 Grammars of the synthesis process (Case Study 1, Designer 3)

9.3.2 Case Study 2: Structured Brief

- Designer 1

Figure 9.5 illustrates the primary and derivative elements that were deployed for the synthesis process and design of the interim artefacts. The following points outline the synthesis process:

- ***Synthesis Process for Each Design Element***

Spatial organisation of functional requirements:

- One proposal for the spatial organisation was initiated in the early phase. Proposal (A_1) is a zoning diagram combined with a spatial concept to separate the main functional elements into three masses linked with transitional zones and circulation elements.
- The concept was deployed to develop another proposal with a slight modification proposing option (B_1). This proposal continued until the imposition of an external constraint requesting a new functional requirement to be included in the final design, where a third proposal (C_1) was

built based on synthesis with proposal (B_1). Proposal (C_1) met the demand and preserved the original idea of proposal (A_1).

Three-dimensional composition:

- One proposal for the synthesis of 3-D form was initiated at the early phase. Proposal (A_2) is a conceptual cross-section in association with the spatial zoning diagram of splitting the mass into three functional spatial elements in horizontal and vertical basis. It outlines the main idea for a universal space including the service areas split between two vertical levels.
- After the imposition of constraint, a proposition of option (B_2) based on synthesis with proposal (A_2) with a slight modification emerged and was deployed to produce the final design artefact.

Circulation and distribution of functional spaces:

- One proposal for the circulation route and distribution of functions was initiated at the early phase. Proposal (A_3) was developed as an extension of one conceptual idea in relation to proposals (A_1) and (A_2) at the initiation phase. This concept for circulation was preserved even after the imposition of the constraint requesting a new functional element.

- ***Diversity and Originality***

- The diversity between sequential phases of design was moderate. Similarity was observed between the initiated proposals for the three elements starting from the early phase and passing through the phases of development until the end. The syntheses of the outlined primary elements were based on slight modifications to the original concept without diversifying the solution with new components or broadening the design space.
- The probability for crossbreeding was higher before imposition of the external constraint than after imposition because the emergence of individual conceptual elements taking a bottom-up direction paved the way to create and evaluate syntheses until the end of process.

- ***Design Process Approach***

- This process took a bottom-up direction. Two crucial conceptual elements were designed at the early phase of initiation and framed the concept for the rest of the process. With the imposition of new constraint, a sudden insight to solve the new request emerged but in the frame persevering with the original concept.

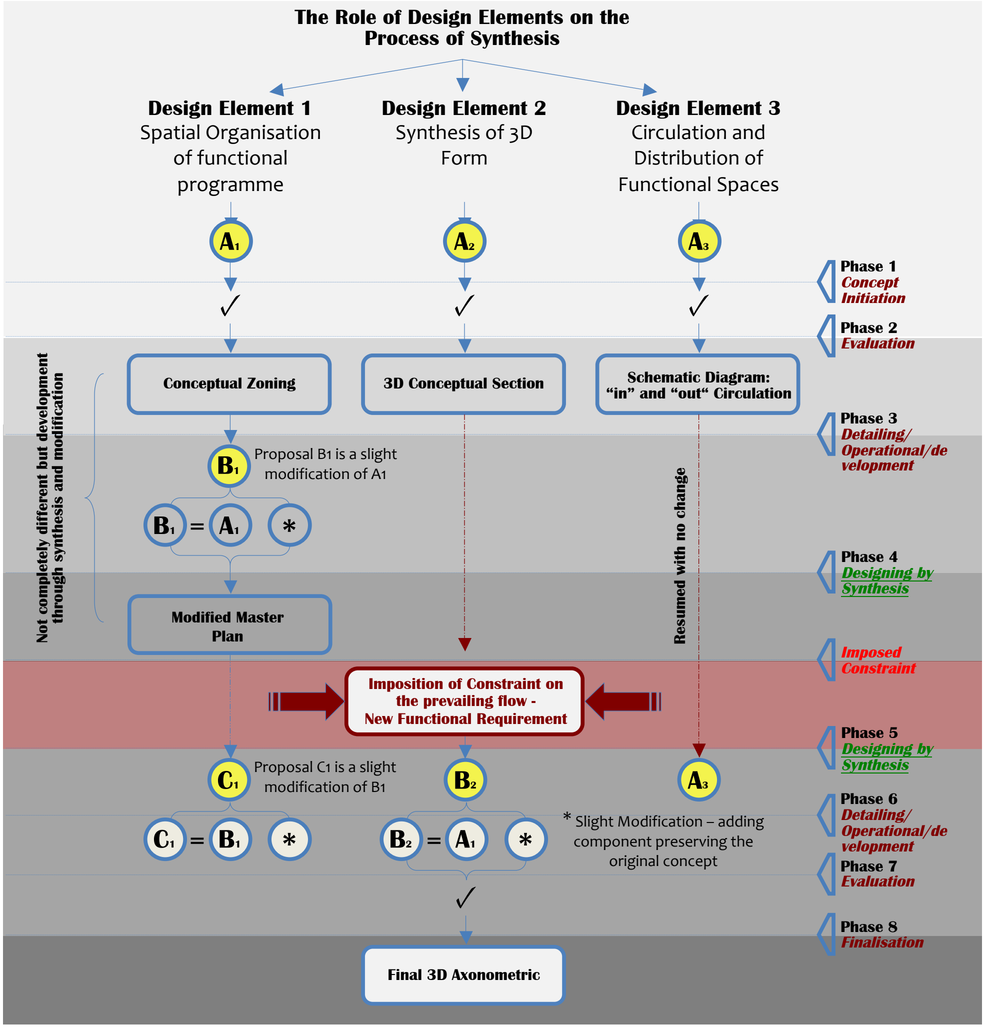


Figure 9.5 Grammars of the synthesis process (Case Study 2, Designer 1)

- **Designer 2**

Figure 9.6 illustrates the primary and derivative elements that were deployed for the synthesis process and design of the interim artefacts. The following points outline the synthesis process:

- ***Synthesis Process for Each Design Element***

Spatial organisation of functional requirements:

- Three types were proposed in the initiation process for spatial organisation: one unit core system (A_1), subdivided core system (B_1), and staggered arrangement of the functional spaces (C_1). The first proposal (A_1) was rejected while a hybrid version between proposals (B_1) and (C_1) was developed as convergence-based synthesis (D_1) and promoted for the following phase of design. This proposition was preserved for the spatial organisation until the imposition of constraint of a new functional request midway through the process.
- Another solution (E_1) for the spatial organisation was proposed synthesised based on proposal (D_1).

Three-dimensional composition:

- One type was proposed for the 3-D form: (A_2) was developed based on the spatial organisation (D_1).

- After the imposition of constraint of a new functional request midway through the process, three proposals to solve the requested condition within the initiated form were explored with the aim of preserving the original concept: proposals (B_2), (C_2), and (D_2). The first two proposals (B_2) and (C_2) were rejected but the third one (D_2) was modified and extended by synthesis to propose another option (E_2) for the final phase. Proposal (E_2) was developed through synthesis process producing the final product and representation of the 3-D conceptual form.

Circulation and distribution of functional spaces:

- Three types of circulation were proposed in this process: the peripheral route with vertical elements (A_3), the penetrative route with vertically looped access (B_3), and the zigzag route for horizontal arrangement (C_3). The first proposal (A_3) was falsified while a hybrid version of proposals (B_3) and (C_3) was developed as convergence-based synthesis (D_3) and promoted for the following phase of design. This proposition was preserved for the spatial organisation until the imposition of constraint of a new functional request midway through the process and remained as it was until the end.

- ***Diversity and Originality***

- This process was distinguished by the diversity and severalty of proposals of concepts that were initiated at the early phase. Permutations between those proposals paved the way to create syntheses before and after the imposition of external constraint – conceptual proposal 1, the ‘spatial organisation’, and 3, ‘circulation for the distribution of functional spaces’. Aiming to develop the concept and achieve the specifications of functional programme, *crossbreeding* between the proposals helped to test and evaluate the interim products through the syntheses, take decisions accordingly and reach a satisfactory final product between these conceptual aspects.

- ***Direction of the Design Process***

- This was a top-down process; the conceptual form of the mass including the 3-D form and the external peripheral of the master plan were set at the initiation phase. The proposed solutions for the spatial organisation and distribution of functional utilities and spaces were all explored, evaluated and tested in the initiation phase. This was followed by an operational development phase to design the details with respect to the initial frame of the conceptual form.
- After the imposition of external constraint, more proposals were explored with the aim of including the new functional requirement in the final design. The developed proposals preserved the original concept, which was slightly modified to achieve the requested demand.

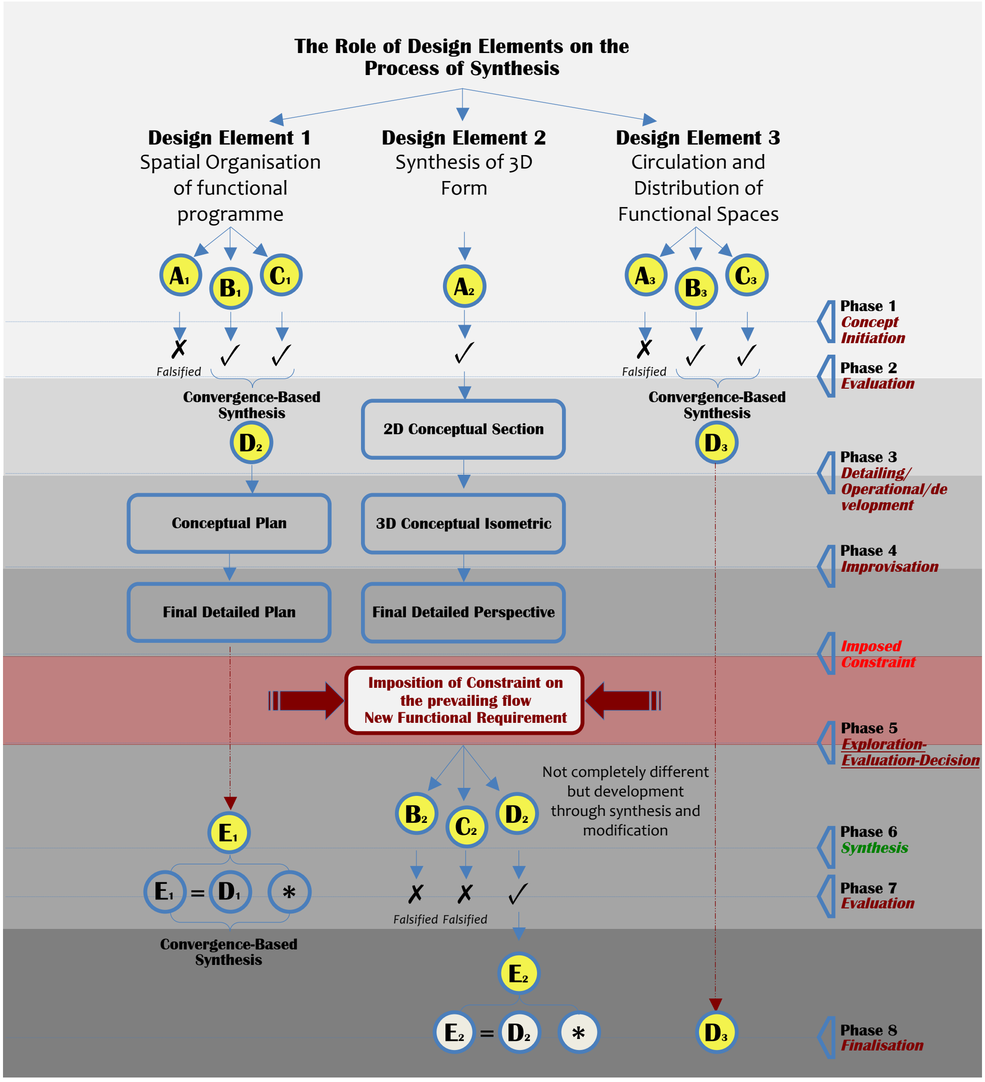


Figure 9.6 Grammars of the synthesis process (Case Study 2, Designer 2)

- Designer 3

Figure 9.7 illustrates the primary and derivative elements that were deployed for the synthesis process and design of the interim artefacts. The following points outline the synthesis process:

- ***Synthesis Process for Each Design Element***

Spatial organisation of functional requirements:

- One proposal for the zoning composition (A_1) was initiated in the early phase echoed in 3-D conceptual form (A_2) and restated in the circulation proposal (A_3).
- The spatial organisation was set at the first iterations on a sketch and directly transformed to a 3-D perspective implemented with high-calibre sketching and signified with a structured imagination after the initiation phase. After the imposition of the constraint, the initial spatial proposal was omitted and divergence occurred leading to a new proposition (B_1) that was evaluated, developed, modified by adding another component and finalised to become proposal (C_1).

Three-dimensional composition:

- One proposal for the synthesis of 3-D form (A_2) was built synchronous in relation with proposal (A_1) for the spatial configuration. This proposal was consistently developed and finalised just before the imposition of an external constraint.
- After the imposition of external constraint, proposal (A_2) was modified and extended by synthesis to propose another option (B_2), which was proceeded on and developed to produce the final outcome of the 3-D conceptual form.

Circulation and distribution of functional spaces:

- One preliminary circulation proposal (A_3) appeared later in the process after the imposition of an external constraint then was changed because of the divergence occurring to another proposal (B_3).

- ***Diversity and Originality***

- Perseverance in one concept through the stages continued until the end of the process. This was shown by high-calibre freehand sketching skills causing creative leaps, transferring the concept into spatial form configuration.
- Diversity was achieved after the imposition of external constraint; divergence from the original concept was experienced and led to reintroducing a new design situation restructuring the preceding content in a different way. The final product was distinguished from the interim artefacts before the constraint's imposition through the primary design elements: spatial organisation, 3-D form, and circulation and distribution of functional spaces.

- ***Design Process Approach***

- This process was top-down directed; the main conceptual outline and form were determined at the early phase of design. The design problem was then decomposed into minor subsets of architectural solutions and the internal functional spaces were designed and detailed within the main form.
- However, after the imposition of an external constraint, the process took a top-down direction again. The main conceptual form was redesigned then internal functional solutions were designed afterwards.
- This approach to designing paved the way for perseverance in the concept limiting the chances for reflective actions to reform the original idea in a bottom-up direction.

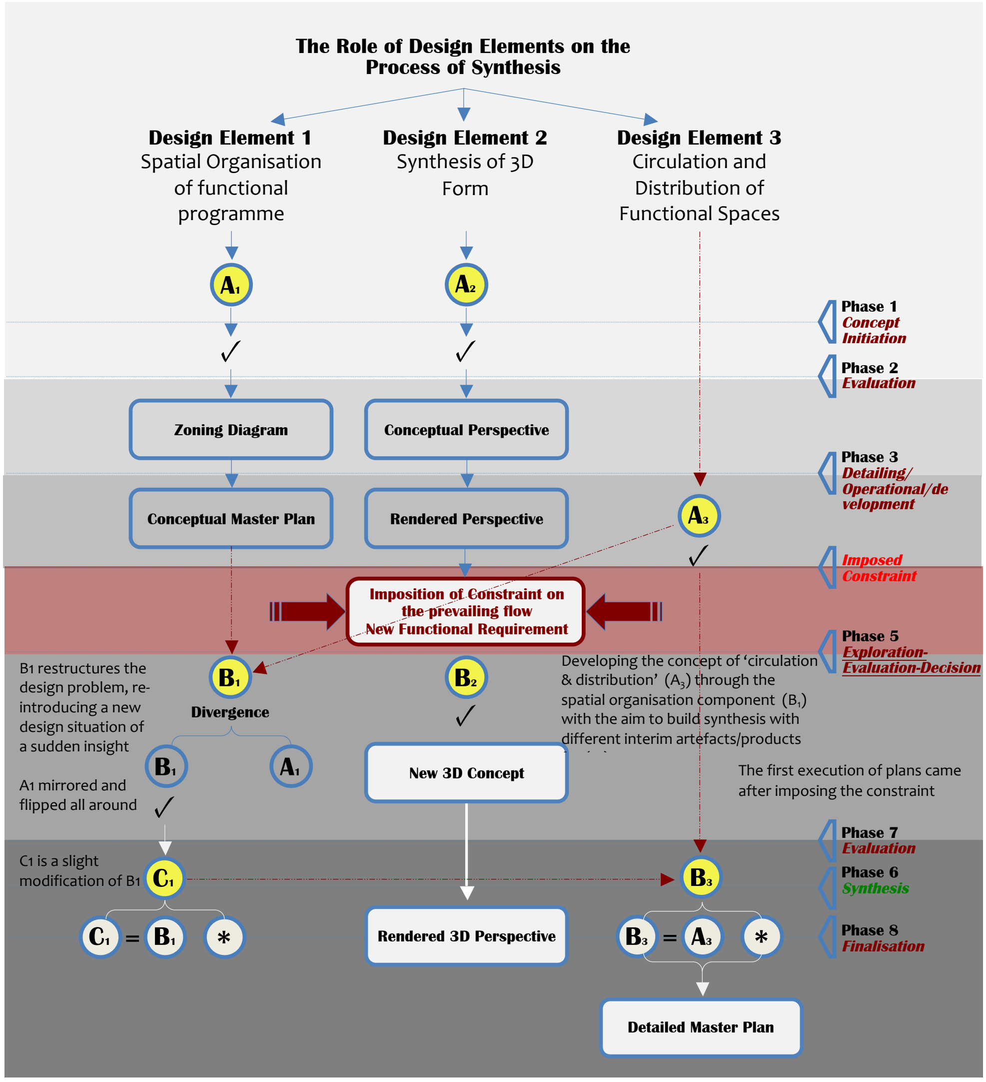


Figure 9.7 Grammars of the synthesis process (Case Study 2, Designer 3)

9.4 The Cognitive Styles for Invitee Architects in the Configurations of Linkography

We have proposed a descriptive model with the aim of distinguishing between two primary concepts; the creative qualities for design actions are classified as 'defying' or 'preserving' the prevailing concept – adopting the model of Sternberg and Lubart (1995).[99] Further, investigating the role of sudden mental insights on design reasoning has revealed two major principles to consider. First, this phenomenon acts to change the design problem landscape into becoming more probable for forming solutions instead of actually solving the problem (see Chiang, 2006: 2). Second, sudden mental insights occur after experiencing an impasse or *fixation* effect (bottleneck) that stagnates the mind to generate the convenient solution for the specific problem.

Thus, the proposed model is an indicator to distinguish between *divergence* and *convergence* thinking and the implications for the role that creative actions play in the structure of reasoning process: *reframing the solution* versus *restructuring the problem*. This study provides a qualitative analysis to read the implications of design thinking processes on the configurations of linkograph patterns.

[99] Sternberg and Lubart proposed that creativity is something everyone has similar to intelligence and that it can be developed. In their model, entitled 'defying the crowd', they targeted examples of average people and their ability to be creative, asserting that most people can be intellectually inventive at some level,

We identify two poles to distinguish linkography patterns: *diversification* versus *integration*. While diversification reflects *divergence* and *severalty* of design ideas, integration reflects *articulation* and *convergence*. While creating a variety of *diverse* ideas could lead the design process to a *disordered*, *ambiguous* and *incoherent* state, which appears in the form of *disconnected*, *intermittent* and *parsed* linkography patterns, generating highly *integrated* ideas might lead to an *ordered*, *systemic* state, which appears in the form of *interconnected*, *interrelated* patterns (Kan and Gero, 2009a, 2009b, 2009c).[100]

Starting the design process with the generation of *independent* conceptual elements paves the way for *synthesis* processes to take place in the long term in the design process, which increases the probability of diversifying the linkograph and creating *deeply structured* patterns. However, the perseverance of one primary concept all through the process, adopting a *hierarchical* design approach, increases *convergence* and might lead to extending the *fixation* effect.

The ideal state of design is dependent on *cohesiveness* and *incubation* of ideas that possibly lead to a structured pattern. From the detection of the variety of linkography patterns that are constructed for the design experiments, two major types of processes are concluded: the *insightful process* is characterised by the concept initiation phase that generates different conceptual elements and creates syntheses between them along the design discourse. The *incremental process* is characterised by the perseverance of one prime concept and predefined set of goals that has to be achieved along the design discourse. In Tables 9.4, 9.5 and Figure 9.8, we summarise the main characteristic of each type of process through the case studies.

[100] Kan and Gero (2009a, 2009b, 2009c) discussed in detail in Chapters 4 and 5 of this thesis.

Table 9.4 Free-style, unstructured design task – expo pavilion

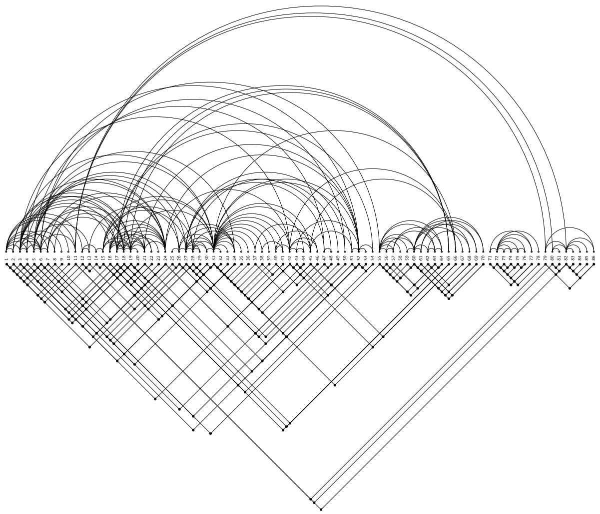
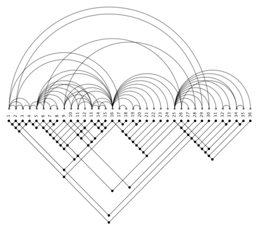
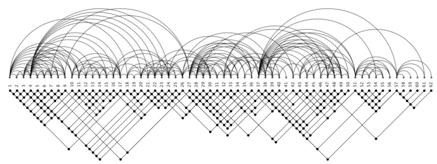
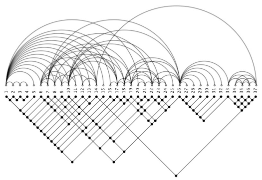
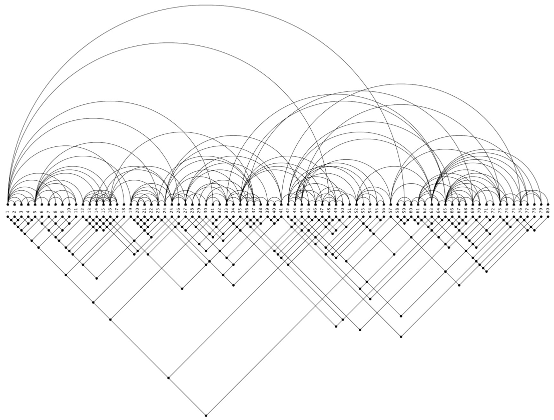
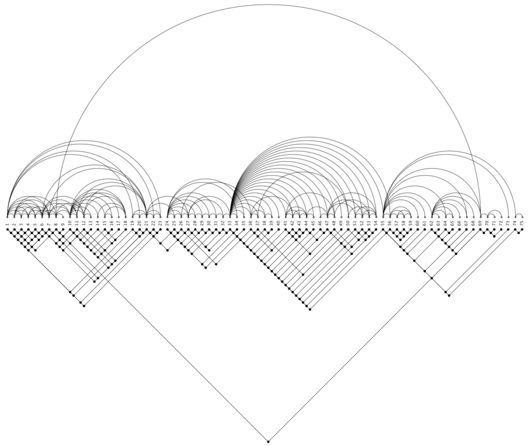
Subject 1	**Subject 2**	**Subject 3**
		
▪ Insightful process ▪ The pattern's disparity owes hierarchical transformation of the idea from a medium to another ▪ Long back and fore linking between earlier thoughts and the ending phases of the process ▪ The linkograph is split at node 71 because of a sudden insight emergences has divided vertically transformed the preceding idea to a totally new one.	▪ Insightful process ▪ The overlapping between chunks of nodes is somehow limited but there are few linking nodes (bridging between media sketches) in which reflects vertical transformations on the concept along the process ▪ Long back and fore linking between earlier thoughts and the ending phases of design	▪ Consistently Structured incremental process - Dense pattern ▪ No long back and fore linking - merely transitional from a chunk to another ▪ No sudden insights to split the pattern into semi disconnected sub-networks. The pattern is compact, overlapping and dense. It reflects an adherence to one concept through dominating the process with lateral form of transformation

Table 9.5 Highly structured and constrained design task – cheese factory

Subject 1	Subject 2	Subject 3
		
▪ Insightful process ▪ The pattern's disparity owes hierarchical transformation of the idea from one medium to another ▪ Long back- and forelinking between earlier thoughts and the last phases of design	▪ Insightful process ▪ Long back- and forelinking between earlier thoughts and the last phases of the process ▪ The pattern owes lateral and vertical transformations on the conceptual idea along the process	▪ Consistently structured incremental process. The pattern is dispersed to some sub-networks and the overlapping is very little ▪ No long back- or forelinking except one link to retrieve a 3-D conceptual idea from an earlier representation (2-D-sec) ▪ No significant sudden insights to split the pattern but there are some bridging nodes especially when switching between two different media sketches

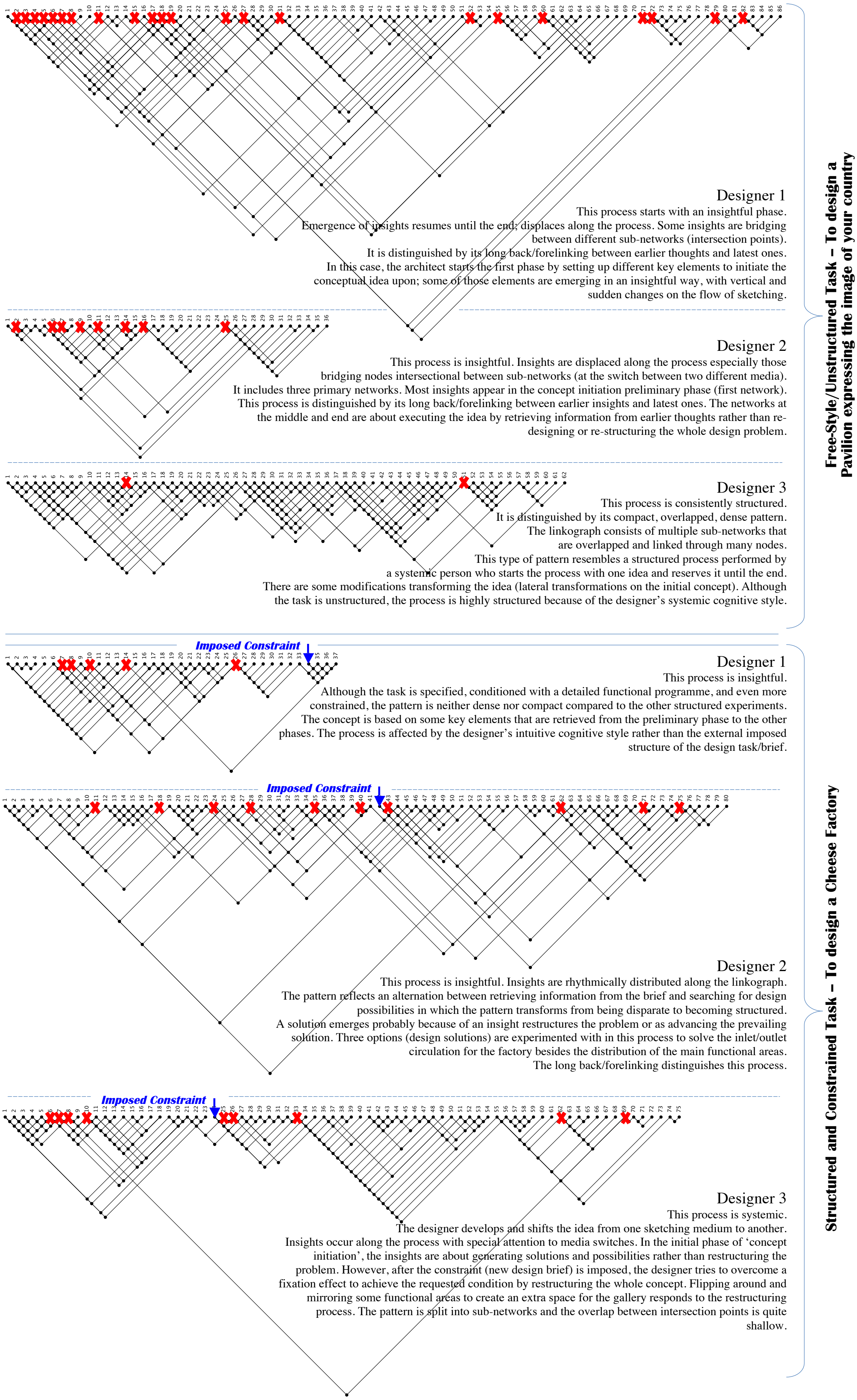


Figure 9.8 Insightful versus consistently structured processes

Another important factor to consider in this study is *incubation* versus time of *externalisation*. Incubation occurs whenever fixation dissipates. Finke et al. (1992) stated that incubation refers to a case in which the design problem is set aside temporarily after an initial impasse is reached.[102] Reporting on the failure to solve a problem through the initial attempts, Perkins (1981) debated that incubation helps the sudden realisation of ideas at unconscious level.

Yet another factor is the cognitive style of each architect. In their study, Sagiv et al. (2009) reviewed two opposing views to investigate the creative process in business management. The first is the 'situational' perspective, where organisations construct tasks and set conditions for enhancing creativity among employees. The second is the 'individual' perspective, which looks at cognitive structure on a personal level and the variety of cognitive styles between individuals.

In the 'situational' perspective, the performance of individuals under structured conditions is better than in totally freestyle tasks in terms of creativity and generation of unconventional solutions. It assumes that individuals who are trained with structured methods perform better than those trained with freestyle methods. However, this view does not claim that design restriction may enhance or undermine creativity; rather it points out the conditions of context that are needed to advance creativity. According to Sagiv et al. (2009):

- Creativity results from restricting the space of possibilities in various means that leads to focus on the central elements of the problem.
- Limiting the number of variables from a large set to a more manageable number of core components advances creativity.
- Constraining the space of thought may decrease the number of ideas but should increase creativity.

In the 'individual' perspective, although differences in the structure of thought between individuals distinguish creativity performance, it is debated that:

- Creativity is directly associated with *intuition* rather than *systematic* cognitive style.
- Personal attributes involve *individual* differences in applying the structure and are therefore conceptually related to the 'freestyle' structure rather than the 'systematic' one.

Creativity in the situational perspective is viewed as a systematic type of linear (incremental) thinking; each design action stems from the preceding one by reasoning from logic rather than intuition. It is reproducible, recursive, based on rules, and an outcome of ordinary thinking. Creativity is hence distinguished according to the 'products' and outcomes of design, not by the 'process' of how it was produced.

It is debated that the imposition of structured constraints stimulates creative insights rather than creating a context of entire freedom to the individual. However, in the 'individual' view, in contrast to the 'situation' view, creativity is 'context-dependent' and positively associated with 'intuition', related to a flat hierarchy of associations that uses the individual's imagination rather than stimulating insights from an external repertoire (Sagiv et al. 2009).

According to the individual view, we conclude there are two cognitive styles that capture patterns of knowledge in the design process: intuitive versus systematic styles. Intuitive performance is characterised as capturing a pattern of knowledge that is beyond the individual's consciousness to identify its source and guide the creative thinking (Perkins, 1981). Table 9.6 presents the main characteristics of intuitive and systematic cognitive styles. In the following section, we aim to shed light on reading the configurations of cognitive styles via linkography patterns.

[102] Perkins (1981) argued that if searching for information continues to produce the same 'incorrect' or 'inappropriate' material, undermining the derivation of appropriate correct material, the inappropriate information is more likely to be retrieved with each consecutive attempt, causing fixation and making the situation worse. Finke et al. (1992) advised setting the problem aside temporarily after experiencing an initial impasse. They argued that the problem can be solved more easily when attention is returned to it later, or a solution may burst suddenly into the person's awareness even without intentionally returning to it. Fixation decreases only when one stops thinking about a problem, resulting in a greater likelihood of retrieving the appropriate information later. This hypothesis considers that sudden mental insight occurs upon the 'collision' between two or more ideas; one that is set in the memory and incubated for a very long time and another that reflects the present state (see Johnson, 2010).

Table 9.6 The characteristics of different design processes according to diverse types of structures

Type of Design Problem	Intuitive Cognitive Style	Systematic Cognitive style
Free-style Design Task (Expo Pavilion)	i) Characteristic of the design process: ▪ Insightful process ▪ Owes lateral and vertical transformations on the conceptual idea ii) Characteristic of the linkograph pattern: ▪ The pattern owes disparity of hierarchical networks ▪ Long back- and forelinking between earlier thoughts and the final phases of design ▪ The linkograph is separated into sub-networks at some bridging nodes because of sudden insight emerging ▪ Insights are sudden and appear as bridging between sub-networks of media switches ▪ The network is deep	i) Characteristic of the design process: ▪ Structured iterative process ▪ Based on a single concept displaced from one medium sketch to another ii) Characteristic of the linkograph pattern: ▪ The pattern is compact and dense; linking clusters of nodes ▪ Long back- and forelinks between earlier and final stages is very limited; means that the idea is transformed laterally and incremented through the process ▪ Insights are incremental and appear in chunks of links ▪ The network is shallow
Structured Design Task (Cheese Factory)	i) Characteristic of the design process: ▪ Insightful process depends on the intuition of the designer resisting the imposed structure ▪ Owes lateral and vertical transformations on the conceptual idea from one medium sketch to another ii) Characteristic of the linkograph pattern: ▪ The pattern shows disparity of hierarchical networks ▪ Relatively long back- and forelinking between earlier thoughts and the final phases of design ▪ The linkograph is separated into sub-networks because of sudden insight emerging ▪ Insights are sudden and appear as bridging between sub-networks	i) Characteristic of the design process: ▪ Consistently structured process ▪ Based on one single concept developed through the iterative process ▪ Lateral transformation of the idea reflects the adherence on one idea ii) Characteristic of the linkograph pattern: ▪ The pattern is highly compact and dense ▪ Highly linked clusters of nodes ▪ No long back- and forelinks between earlier and final stages (too limited) ▪ Insights are incremental and appear in dense networks and are displaced through the process ▪ No sudden insights to split the pattern into semi disconnected sub-networks

9.5 Configurations of Design Cognition in Linkography

According to the analyses and findings of this study presented throughout the dissertation, particularly Chapters 6, 7 and 8, and the cross-case analyses presented in this chapter, we end this research by providing a prescription to read the types of linkography protocols and distinguish the characteristics of various cognitive styles, forms of reasoning, incubation zones, creative processes and sudden mental insights, where during our investigation we have emphasised the roles of these factors in transforming the design process from one state to another. We aim to illustrate a variety of configurations for the time of 'incubation of ideas' versus 'externalisation and drafting' (execution phases).[103] Through the case studies, we derive a variety of configurations and provide emphases on how could insights contribute to structure the reasoning.

9.5.1 Configurations of Design Reasoning in Linkography

Configurations of linkography are dependent on the phases of design reasoning along the design process until the end. We identify two modes of reasoning, *incremental* and *non-incremental*, where the design process could be configured according to the following hypothetical cases – Table 9.7 and Figure 9.9 present hypothetical scenarios of design reasoning and the effect on the configuration of linkograph:

[103] Appendix 9.1 sheds lights on design education in two societies.

Table 9.7 Configurations of design reasoning via linkography

Hypothetical Case	Hypothetical Scenarios of Design Reasoning	Configuration of Linkograph
1	▪ Design process starts by outlining independent ideas and key elements to initiate the concept. The emergent ideas are likely to be related	▪ Linkograph is structured with interrelated network. If the design process starts with a recursive course of actions, searching the design space for possibilities and alternatives to build the concept on, the events are interrelated in the linkograph creating a quite structured and linked network of relations
	▪ Concept initiation phase includes occurrence of sudden independent breakthroughs; the design actions might be unrelated	▪ Linkograph includes disconnected unrelated events at the early stage that reflect diversity of sources of idea
2	▪ Design process starts with a long incubation period, aiming aim to generate variable solutions and comprehend the boundaries of the problem. Several proposals can be tried, where the design concept is likely to be developed through synthesis and evaluation processes.	▪ Linkograph is structured with long back/forelinking between the various generated solutions.
	▪ Occurrence of sudden insights at the ending stages signifies emergence for the following reasons: *redefinition* of design goals, *restructure* of design problem, and/or convergence between two ideas; giving high probability for a novel idea to emerge and the formation of unprecedented concept in the design discourse. The long time to incubate an idea allows more analysis and decomposition of the design problem into the basic elements and provides possible syntheses to occur between sets of concepts	▪ Linkograph has long backlinks with the early actions or alternatively might be semi- or entirely disconnected from the preceding actions
3	▪ Design process alternates between incremental and insightful phase —from one design phase to another ▪ Design concept is transformed laterally by exploring a variety of pertinent ideas at the incubation phase, incremental phase and vertical transformation follow	▪ An iterative process develops the design concept incrementally and prevails in the initiation phase ▪ This leads to a highly structured linkograph pattern distinguished by dense patterns and long back/forelinking
	▪ However, if an insightful stage occurs in the prevailing flow – distinguished by the creation of synthesis between several conceptual elements – it is possible a drastic change to restructure the design configuration might happen, but most often it establishes a structured process	▪ Creation of unpredicted syntheses might cause a drastic change to the concept development that appears in an explicit disconnection splitting the linkograph. However, syntheses between existing (conscious) elements present a structured linkograph with back-forth linkage
Case 4	▪ Insightful thinking process creates creative hinges that act to foster the conceptual development and direct the design process to explore various possibilities when needed. Creative thinking aims to create an unprecedented novel solution to the discourse. It is supported by frequent alternation between incubation and insightful processes. This alternation in fact increases the hierarchical characteristics of the process and acts to deepen the structure of design process (this can be traced via integration measure). In consequence, this alternation transforms the conceptual idea several times: (1) enriching it at a *vertical level* (incrementing it), and (2) restructuring it at a *lateral level*	▪ Linkograph is characterised by *bridging* nodes that link different chunks of thoughts (links) together. A bridging node could present sudden creative insight, but this cannot be postulated with every bridging event
Case 5	▪ The emergence of a sudden insight can be looked at through the consequences it has on the prevalent discourse. Taxonomy of creative insights is therefore determined from the act they reflect and the structure they impose on the following actions. Incremental insights act on two prime levels: (1) increment the present solution providing more details (generation), and (2) reframes the present design concept. Sudden insights restructure the design problem and redefine the design goals. This type most likely leads to an unprecedented novel idea	▪ In an extreme case, the linkograph is split into two separate chunks of thoughts
Case 6	▪ This hypothetical scenario dictates that the design process starts a setup of conceptual elements, evaluates the best form of synthesis, and then incubates the conceptual idea for a long time without haste to draft the design's drawings ▪ Incubation time achieves better coherence to synthesise the conceptual elements in this phase	▪ Linkograph includes an insightful phase at its early beginning followed by a convergence zone; a bridging node presents the convergence of the preceding events
	▪ An incremental reasoning process might follow an insightful zone; the initial phase leads to exploring unpredicted conceptual elements that require the architect to spend more time to think on how to build syntheses of coherent models for the concept ▪ If more conceptual elements are discovered through long incubation, the initial concept might be restructured again. This is rendered with 'types of sketching' that Goldschmidt (1994) stated: 'transforming imagery into new forms of combinations' as a 'rational' mode of reasoning, and 'generating new imagery of forms in the mind' as a 'non-rational' form of design thinking	▪ Linkograph includes insightful phase; insights might be connected or semi-connected. However, creating syntheses converge those insights through bridging nodes. This is followed by a structured phase that represents incremental reasoning of the concept
Case 7	▪ In design collaboration, the participants of design, architects and multidisciplinary stakeholders (engineers, contractors, suppliers), might consider the design process through parallel modes: processes of *'incubation* versus *externalisation*; *insightful thinking* versus *incremental reasoning*, *free rein* versus *structured knowledge* and so forth ▪ Occurrence of sudden mental insights is likely to occur in the multidisciplinary process due to the variation of expertise and repertoires of thinking. SMIs are more likely to exist in the transformative type of collaborative design process than in the hierarchical mode where one of the stakeholders leads the pyramid of thinking, setting the goals of design separate from the other collaborators	▪ This hypothetical model presents a collaborative process between multidisciplinary groups. In the ideal case, linkograph is characterised by *highly structured* coherent network as well as insights and bridging nodes. Disconnecting events to restructure the design problem might occur in the case of experiencing unpredicted problems, fixation and impasse

Different variables are involved in the design collaboration process. Variation in expertise and knowledge between collaborators, design discipline and experience, synchronic and asynchronic thinking, leadership and authority control, platform of collaboration, geographically dispersed or co-present and so forth are all confounding variables that contribute to design collaboration and authorship of novelty.

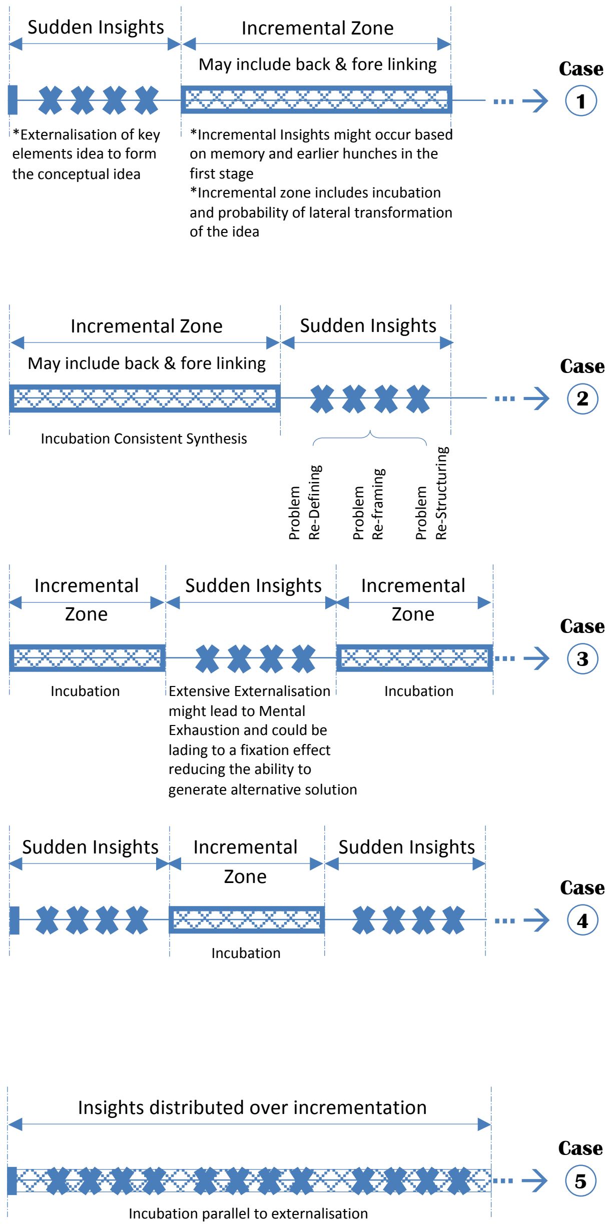


Figure 9.9 Hypothetical scenarios of design reasoning

9.5.2 Length of Incubation Period in the Evolution of Ideas

From our investigation and ethnographic observations of the case studies, we outline three models to emphasise the relation between the length of incubation period and externalisation and operational phases of design, e.g. drafting, sketching and drawing detailed precise products. Incubation time is assumed to achieve better coherence to synthesise the conceptual elements in this phase. These hypothetical scenarios can be seen in Table 9.8 and Figure 9.10.

Table 9.8 Configurations of design reasoning via linkography

#	Proposed scenarios for period *of Incubation* versus *Externalisation of ideas*
Model 1	▪ Concept initiation might show short time of incubation where the architect rushes to externalise the idea and design drawings.
Model 2	▪ Concept initiation phase might show long time of incubation where the architect spends more time to think of the possible concepts of design then executes the idea through drawings.
Model 3	▪ Design process might alternate between incubation and execution phases due to the effect of emergent creative insights. ▪ The process is hierarchical due to multiple transformations and lateral displacements in the conceptual idea. The more insights emerging – making the process explore different options and goals – the more the design process becomes structured. Bottom-up design process makes it transformative – setting the goals and descending the process to achieve them makes the process hierarchical. This type of alternation most likely leads to the generation of creative solution. ▪ However, a cascade of unrelated, entirely independent insights might cause *hyper-stimulation*, where the architect shifts from one state to another without developing the original concept configuration.

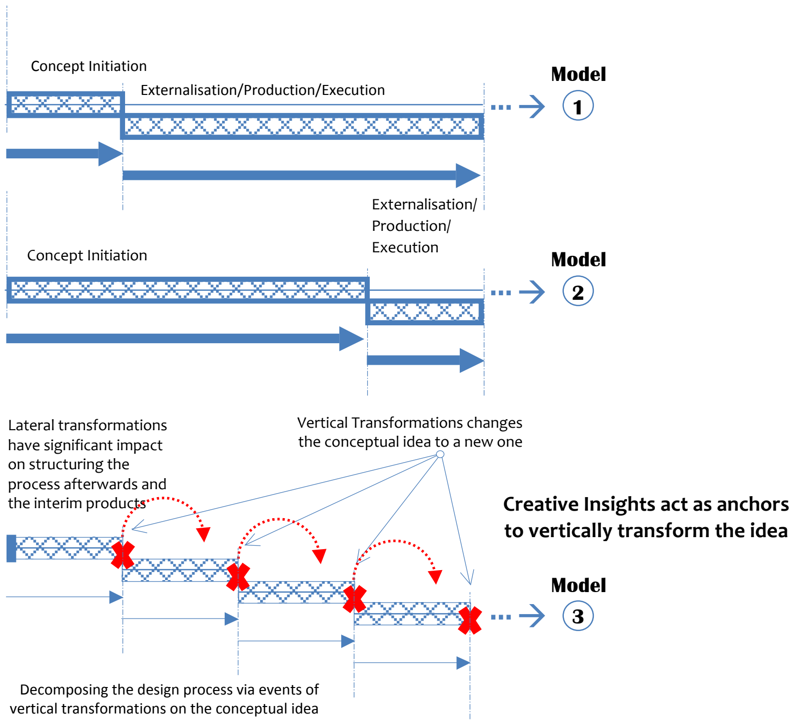


Figure 9.10 Incubation and the evolution of creative (sudden) insights

From the design experiments presented in Chapters 6 and 7, we argue that the occurrence of an insight imposes a kind of structure on the following actions and directs the design process to execute a certain concept through the following products.

Figure 9.11 shows various examples of pivotal actions that appeared in the six experiments and directed the design process and pertinent products to achieve certain features of the emerging concept.

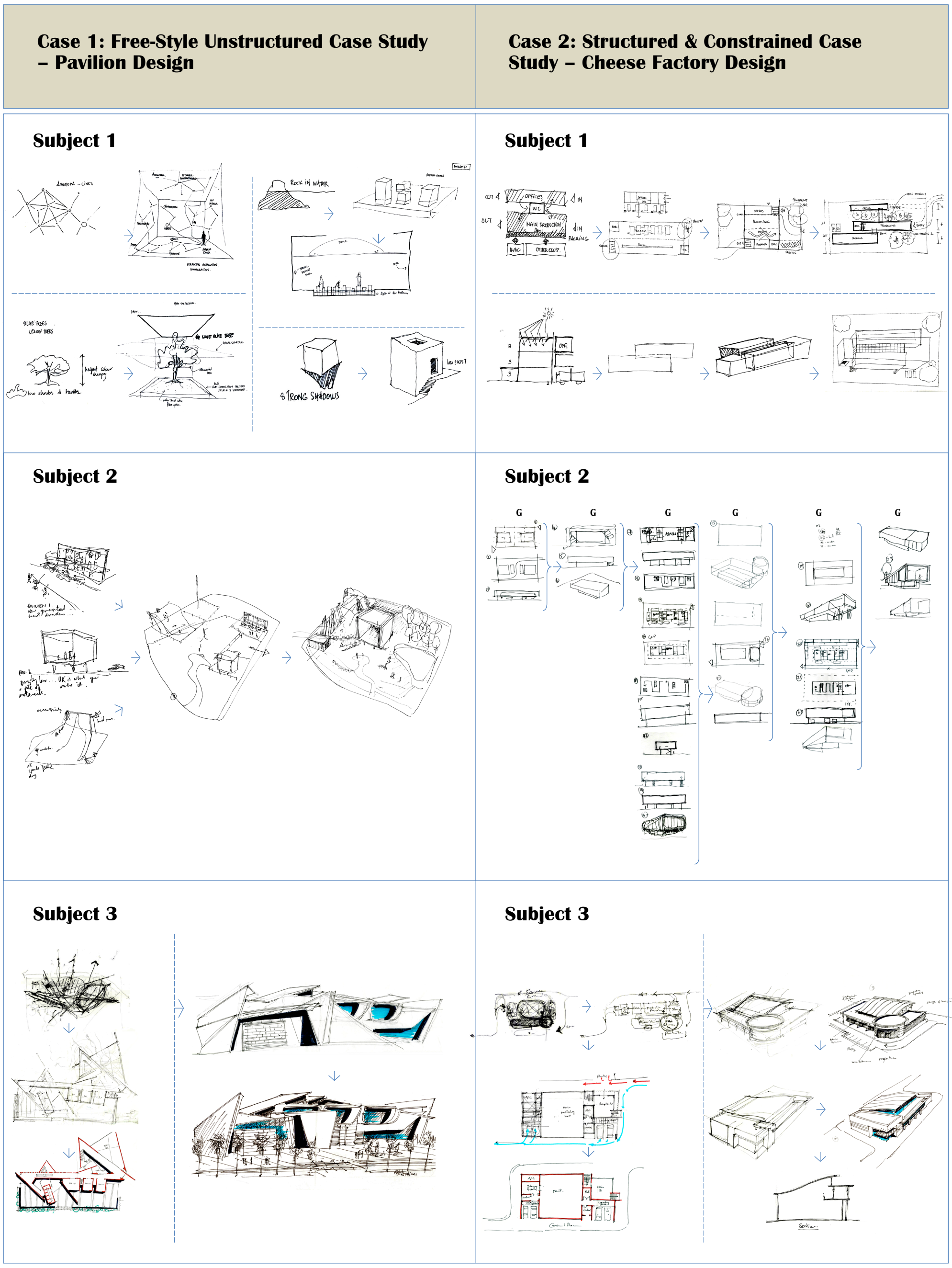


Figure 9.11 The role of creative insights on the structure of reasoning and interim artefacts – Products for the six design experiments

9.6 In Conclusion

This chapter identifies some important aspects of the results of experimental case studies for discussion: models of synthesis, grammatical representation of the conceptual elements in the synthesis process, and configurations of a variety of design thinking and cognitive processes via linkography patterns.

Syntheses between conceptual elements, the generation of solutions and evaluation processes signify the architect's style of design cognitive thinking. Rational thinking can be identified through the perseverance of one conceptual idea all through the design process, which is developed through a series of cumulative and correlated steps and is characterised by a dense linkography network of short links. Non-incremental thinking of a non-systemic style diversifies the permutations between conceptual elements, presents divergence, and is characterised by a structured linkography of long back- and forelinks.

Creativity exists in both intuitive and systematic thinking processes. Intuitive designers rely more often than systematic individuals on the unconscious mind. The intuitive person tends to capture a pattern without being able to account for its source; unconscious pattern guides the train of thoughts. Intuitive style imposes 'in/out' patterns on the design process. Systematic designers pursue logical analysis of the situation to tackle the design problem. The systematic person adopts rational models and identifies rules to evaluate the design proposals. A creative solution is generated under structured conditions. Systematic style imposes 'out/in' patterns of the structured knowledge on the design process.

To this extent, It should be noted that the intuitive or systematic cognitive styles cannot be specifically correlated with incremental or non-incremental reasoning processes, and we cannot postulate that intuitive thinking is non-incremental and that systematic thinking is incremental, or vice versa. The reason is that other confounding variables are involved in the design process: unconscious versus conscious mind, talent and imagination, mental versus external representations and so forth. According to the results of the design case studies, we conclude three configurational types of synthesis between the conceptual elements: first, proposing a novel unprecedented element that is first introduced to the design process reflects independence and divergence; second, hybridisation between two or more existing elements reflects dependence and convergence; and third, modification of an existing element by adding partial elements to it.

This research does not try to answer the question that was posed earlier by Ward et al. (1999: 189) concerning *structured* versus *unstructured* creativity: 'Are creative insights normally derived from existing cognitive structure and representations, or are they chanced upon arbitrarily?' However, it is important to shed light on the debate and pave the way for future work.

This study has presented many inferences on structured creativity, but this is conditional on examining the phenomenon in a larger number of experiments to generalise the conclusion. First, the imposition of a certain structure of actions on the following stage after the emerging sudden insight can be considered a sign of structured creativity. Second, the emergence of insight that appears to come from nowhere ('out of the blue') is still unproved and requires firm evidence. The present argument is that the context beyond the emergence of mental insight can be rooted in the subconscious mind even if the resulting product is not traceable through the observed cognitive actions in the preceding design process.

9.7 Key Findings of Chapter Nine

- Creative design process correlates to the variety of conceptual elements at the initiation phase and syntheses with the aim of generating a variety of proposals and products of *diversity* and *originality*.
- Implications of sudden mental insight can be investigated through models of synthesis by determining the main aspects of concept and design configuration (e.g. spatial organisation of functional requirements, 3-D composition, circulation and distribution of functional spaces).
- The proposed method of *grammatical representation* of the conceptual elements and synthesised products presents a profound insight into the design configuration, the development of design concept and the impact of imposed constraint on the structure of design reasoning.

Chapter

10 In Conclusion

Contribution to Knowledge and Implications to Professional Stages of Work

This dissertation contributes to knowledge in two areas of design research: the first is a methodological development to propose a quantitative and qualitative analytical framework of directed linkography that aims at describing and capturing the structure of events taking place in the design reasoning process; the second is an investigation that aims at interpreting the formation of novel concepts in architectural design by detecting the role of procedural and contextual components in the evolution of creative ideas and mental insights from the perspective of creative cognition.

Using detailed ethnographic observations of designers working on architectural design tasks, this empirical study investigated design reasoning in two briefs presenting different design problems: the 'freely unstructured' versus 'specified structured' (specified with functional requirement and imposition of unexpected requests functional programmes) design briefs for solo design processes. Reflecting attempts to understand the design process through different schools and paradigms of research, two controversies were discussed: the relation between the 'design contents' and 'structure of reasoning' ('hierarchical' or 'transformational'), and the 'role of SMI phenomenon in creative thinking'. Light was shed on views on 'technical rationality' versus 'epistemology of practice'.

A descriptive method has been developed during the study to transcribe, segment, and code the design process into useful episodes not only to capture the structure of reasoning, but also to detect the rates of quality of creative contribution to concept development, value-added to the decision making process, and effect of design configuration in the overall structure. This method considered the aspects of 'reflective practice' and 'the gradual transformation of mental imagery' to monitor the critical venues of transformation and demarcate the occurrence of sudden change from one state to another in solo design and collaborative processes. It also discussed the effect of media of communication on the bandwidth between the designers in remote collaboration.

This study investigates the question: Is design best described as a procedural entity or as contextual actions of environment and affordances? Procedural and contextual components are accordingly addressed in three configurations of linkography; order, structure and disorder. The context beyond the emergence of creative insights is twofold: on one hand there are insights that emerge in incremental reasoning to reframe the solution (prevailing concept), and on the other there are sudden insights (eureka and a-aha moments) that emerge in non-incremental reasoning to restructure the design problem and reformulate the entire design configuration. Accordingly, two types of cognitive styles are coined in the design processes. Some architects define the design problem and concept at the early phase of thinking process, set up the goals, and show high perseverance on framing and reframing this original setting all through the design process to the end. On the other side, there are architects who initiate the design process by designing a variety of independent conceptual elements and then proceed to form syntheses for the spatial configuration among them. Sudden mental insights are most likely to emerge due to the unexpected combination of synthesis, particularly in the latter case. Framing, reframing the solution events versus restructuring the design problem denotes two roles of creative insight in the reasoning process of creative discovery. Finally, this chapter draws directions for future research development in the field of design research and creative cognition.

10.1 Discussion

The aim of demonstrating the paradigms of research into 'technical rationality' and 'epistemology of practice' (Chapters 1 and 2) is twofold: to understand the nature of architecture design process, and to distinguish the variety of design models according to the main findings of research in the area. We proposed a descriptive method and examined the validation across design experiments. This proposition aimed at bridging the gap of miscorrelation between quantitative and qualitative analysis to describe a design situation as the main aspect of 'reflective practice' in the design process. This correlation plays an important role in identifying the critical moves, creative insights (eureka, a-ha moments) and evolution of ideas (formation of novel concepts) and investigating the role of the *procedural* and *contextual* components in concept development and reasoning process.

Creativity is to create a new unprecedented idea that adds 'value' to the design discourse, defined by Newell et al. (1963) as 'Creativity = Innovation + Utility'. In our approach, a creative idea is evaluated for the value it contributes to the formation and synthesis of the subsequent actions, idea generation and concept development of emergent artefacts. Considering design as a *reflective practice*, which is a supposition in understanding design creativity. The more mutual interplay there is between design's interim artefacts (internal and external representations of cognitive structures), the greater the probability of new ideas evolving. A sudden mental insight imposes a structure of thoughts and actions on the subsequent events in the design reasoning process. This can be tracked, via the bridging nodes in the linkograph, for the relation between spatial forms, ideas and solutions of similar entities and evolving products. A paradigm shift is a drastic change that may restructure the whole design problem and imply consequences for reformulating the entire situation. Sudden mental insights play an imperative role in this particular event that can be tracked by distinguishing the difference in concept development and evolving artefacts before and after emergence. This role can be detected through the integration of quantitative and qualitative analyses from one design situation to another.

To understand and address the main principles for the proposition of descriptive method, attempts that aimed to identify the context behind the occurrence of sudden insights are considered through *Gestalt* versus *technical rationality* views, such as the theories of Akin and Akin (1996), Csikszentmihalyi (1996), Koestler (1964), Schön (1963, 1983) and Sternberg (1994, 1999, 2003).

In our proposition, we consider the 'epistemology of practice' view to describe the design situation; if the generation of a creative idea (solution) to a particular problem can be predicted in the early phase of thinking (concept initiation) or not. Accordingly, we aim to identify the events of unexpected discovery that are hypothesised as responsible for the formation of novel concepts with a high quality of creative contribution. Identification of the role of sudden mental insights in the design process is proposed to unfold the controversial relation between 'contents' and 'reasoning' in the design process. Two points are addressed while investigating the types of relation: first, Rittel and Webber's definition (1973) of a design problem as 'ill-defined' in the context of architectural planning, where the problem is framed through the multiple reflections within the design brief; and second, the many views forming the debate on creative discovery and associated phenomenon in design reasoning processes.

This analytical method aimed to capture the structure of events and critical actions that take place in the design reasoning process. Models of 'linkography' (Goldschmidt, 1990, 2014; Kan and Gero, 2005a, 2005b, 2005c, 2008), 'macroscopic cognitive scheme' (Suwa et al., 1998a; 1998b), Shannon's 'entropy' (Shannon, 1984) and 'deterministic information theory' (Titchener, 1998a; 1998b; 1998c, 2004) were tested in the attempt to transcribe, segment and code the design process into episodes. We found that the association between creative events and high entropy values cannot be generally postulated to interpret the formation of novel concepts in architecture design.[104] We introduced a qualitative approach to judge the 'gradual transformation of concepts', 'emergence of sudden creative actions' and 'drastic shifts' occurring in the design process, which reflected both 'low' and 'high' entropy values in the variety of case studies. This extended our investigation to develop the quantitative model to re-examine the findings through different schemes, i.e. t-codes (strings of information), syntactic analysis (depth measures), and network analysis (centrality measures). A variety of configurations in linkography have been identified through the proposed method to correlate between the qualitative and quantitative investigations.

In the first attempt to develop a descriptive method to investigate the design process, integration was made between 'linkography' (Goldschmidt, 1990) and 'macroscopic cognitive scheme' (Suwa et al., 1998a, 1998b) to segment and code the dependency relations. However, this approach showed a drawback in that each scheme is based on specific definition of a segment and a dependency code. We were challenged by the methodological question: 'is it possible for each scheme to identify and capture the same units of design in the structure of reasoning?' We found that the precision to identify moves, cognitive actions or designing episodes in both schemes was different, reflecting dense relations and tiny segments to some extent that might flatten the resulting linkograph.[105] This investigation was extended to deploy the function-behaviour-structure (FBS) (Gero, 1990; Hybs and Gero, 1992; Gero and Kannengiesser, 2004); however, it was difficult to distinguish those three aspects in architectural design process and to overcome the effect of the confounding variable of the architect's 'idiosyncrasies' resulting from the affordances to the design situation (action of environment) while coding the relations. Aside from the FBS model's reading of the evolutionary and cyclic nature of design, our intention was to

[104] Refer to the discussion held on hypotheses 'A' (Goldschmidt's definition of the 'critical move' and 'productivity', 1990) and 'B' (Kan and Gero's assumption of creativity in the richness of links to be indicated via Shannon's entropy, 2005a; 2005b; 2005c, 2008) in Chapter 4.
[105] See the evaluation process of the joint model and of the developed proposition in Chapter 4.

implement the non-discursive and non-linear (holistic) nature of architecture design while developing a methodological analytical approach for empirical study and ethnographic observations.

The invited participants were introduced to two different types of design tasks. One was an 'open-ended', 'freestyle', and unstructured design brief to design an Expo Pavilion. The other had conditional requests and functional specifications to design a Cheese Factory. The first type allowed the designer to use his/her subjective interpretations and intuitions to create the design concept, while the second was outlined to require the designer to follow an objective and logical context of design process.

One main objective of this research is that it bridges three main fields: 'design research in architecture practices', 'creativity' and 'human cognition'. There are many studies aiming to identify the relation between the three fields, but our endeavour intends to contribute knowledge about design, like Cross's claim of 'designerly ways of knowing' (Cross, 1982, 1984, 2006), as an alternative to both technical rationality and epistemology of practice, by uncovering empirical evidence on the nature of design processes.

A variety of actions can be observed and denoted in the series of design events that comprise moves: *cognitive actions*, *idiosyncrasy* and *designing* (sketching) *episodes*. We were able to code the dependency relations among design actions in a series of attempts, consolidated by the 'propulsion theory of creative contribution' (Sternberg, 1999, 2003).[106] Through this approach, it has become possible to identify precisely the critical moves and detect the evolution of creative ideas that contribute to the formation of novel concepts. It has also become possible to detect the role of sudden mental insights and deduce the relation between contents and structure of reasoning. This empirical study identified different configurations for the evolution of ideas in the design reasoning process where the conclusions are twofold:

First, there is no one predefined style, form of reasoning or structure the architect would adopt for the design process, and therefore to suggest a prescriptive model that anticipates the evolution of creative ideas, formation of novel concepts and innovation of design products would not capture the real state of creative discovery in the thinking process.

Second, any design process comprises procedural and contextual components; the former are the parts or subsets of the design problem for synchronic concept development or implementation of the conceptual idea (local scale, in progress), while the latter relate to the whole design problem for concept synthesis of back- and forelinking between the diachronic stages of the design process (macro scale, in progress). The contextual components look at the overall design process whereas the procedural components look at the local situation in the design process.

10.2 Implications on Understanding the Nature of Architectural Design Process

The empirical study provided evidence on several important points to understand the nature of design processes and enriched the debate on some controversial points that were introduced in the literature chapter. Some of the hypotheses that were put forward are proved as follows:

Designers deployed a variety of design approaches that are mainly solution-focused to formulate the design problem, generate and develop the concept in the design experiments. Two main strategies were obviously deployed in the empirical cases: some architects define the design concept early, set goals and persevere in framing and reframing this until the end, whereas others initiate the concept by designing independent conceptual elements and then proceed to form syntheses for the design configuration. Sudden mental insights are most likely to emerge from the unexpected combination of synthesis, particularly in the latter style.

Synthesis and *analysis* started early in the design process and are identified as meaningful discrete component of design. The designers analysed the situated problems all the way through the design process and generated solutions by synthesis from the early stage of the concept initiation. Goals and design constraints are redefined all the way until arriving at the satisfactory outcome of solution.

[106] Examples of the initial attempts of transcription and coding are included in Chapter 4. Final transcription and coding models for two different sets of design experiments are included in Appendices 6.1, 6.2, 6.3, 7.1, 7.2 and 7.3.

They initiated the conceptual idea based on a set of objectives, featured as the primary generator, and then reduced the set of solutions to a smaller manageable class to conjecture a solution. In each case, the solution was tested against the design requirements (by revisiting the design brief) and further improvements were made.

Design is *structured with the bodies of knowledge*; a pre-occupation of geometrical patterns and predefined configurations of functional elements to structure knowledge. A pattern or some other ordering principles were added to the information in hand to arrive at a unique solution. This pattern pre-occupation can be also understood in the process of conjecturing a solution; *pattern constructing*, *conjectured solution and refutation process* as a 'preconceived form' to generate a solution.

The solution is *not chanced upon arbitrarily*; to initiate a creative design concept is to start from a conceptual basis. To express the case of the 'creative' event, a chunk, or seed, of information is formed in the assignment information that helps to crystallise a 'core' solution ideas. This core solution idea changes the designer's view of the problem. Creative design involves a period of exploration until the reformulation of an emergent bridge that identifies a 'problem-solution' pairing (Dorst and Cross, 2001).

A creative event occurs as the moment of sudden insight at which a problem-solution pair is 'framed'; 'problem by framing' (Schön, 1983). Framing ability is a skill of the creative designer (Paton and Dorst, 2011). The 'creative' aspect of design can be described by introducing the notions of 'default' and 'surprise'. According to Schön (1983), the notion of 'surprise' in creative design has the pivotal role of being the impetus leading to 'framing' and 'reframing' of the 'problem-solution' relation; 'surprise' is what keeps a designer from 'routine' behaviour. Creativity in the design process can validly be compared to such 'bursts' of development and the 'surprising' parts of a problem or solution drive the 'originality' in the design process. The 'process of evolution' can be seen as being driven by a reaction to a 'surprise' rather than a 'gradual changing'.

10.3 Contribution to Knowledge

This dissertation aimed to answer the research question: '*What role do procedural and contextual activities play in the generation of creative insights, critical moves, and the formation of design concepts in the reasoning process?*' by investigating these activities for an empirical study of several architectural design processes. The study explored a variety of design cases with different settings, tools and software. Hypotheses of some models were tested through the development of our proposed descriptive method. Testing some models that are widely deployed in the analysis of design processes has articulated the definitions of 'critical move' and 'link index' (Goldschmidt, 1990, 1991, 2014); 'creative insight' (Akin and Akin, 1996); 'the reliability of a quantitative method to detect the creative "surprising" moments' (Kan and Gero, 2005a, 2005b, 2005c, 2008); and 'the reliability of predefined segmentation and coding scheme into capturing the structure of reasoning and evolving design actions' (FBS model, Gero, 1990; macroscopic cognitive scheme, Suwa et al., 1998a; 1998b).

Consequently, the validation of our proposed method was tested while describing 'unstructured' versus 'structured' design problems. A joint quantitative and qualitative framework aimed to compare the effect of each design action occurring during and after the completion of the design process; this was *directed linkography*, which compares the 'synchronous' and 'diachronic' effects of the emergence of design moves. We were able to represent the grammars of synthesis by detecting the main aspects of the formation of concept for each design process. In view of this, our contribution to knowledge is pertinent to the development of the following lines of enquiry:

- Procedural and contextual influences in the design reasoning process.
- Interpretation of creative discovery and associated phenomena in design reasoning process.
- Directed Linkography Methodological development of a descriptive method to analyse the design reasoning process.

10.3.1 Procedural and Contextual Influences in the Design Reasoning Process

We conclude that the state of design process differs depending on how it is affected by *procedural* or *contextual* components. Design is a 'hierarchical' process when the problem-solving depends on a significant involvement of procedural components to execute the concept and generate the solution through systemic actions. By 'procedural' we mean that each emergent action of reasoning is visited only once to execute a particular entity or form a linear way of 'thinking and executing'.

Procedural components are stage-based and problem-oriented, and neglect any contextual aspects that are associated with reflection-in-action in the design situation. No matter what the design situation is, the solution is generated according to certain actions in the designer's mind. Procedural components are based on the abstraction and analysis of the problem structure that lead to generating solutions and making a choice from a pool of generated solutions. They are primarily based on the formulation of a solution-neutral problem statement, and propose that the final design should be more dependent on logical deduction than on previous experience. Common to all problem-oriented design processes, these characteristics form the basis of procedural components.

In other cases, design is a 'transformational' process when the generation of ideas is based on *contextual* components and *affordances of the environment*, taking into account reflection-in-action to transform mental imagery from one state to another. Contextual components are 'action-centric', design the situation in practice based on 'content-based' decisions, and address the way designers perceive, recognise and experience the problem. Addressing the designer's perception of the emerging problem (to identify the interim goal and generate the possible action of the next step) reveals the core nature of design activity, which exposes the shortage of procedural components. Looking only at the overall components of largely content-based decisions limits the power of the incremental reasoning and procedural components.

A design process may comprise both procedural and contextual components, differing from one situation to another. Procedural components emerge while solving the parts in the design process (details of concept); contextual components distinguish the overall structure by looking at forms of synthesis to link between the chunks of ideas thoroughly and form the whole design concept. Both components can be detected in our methodological development of the configurations of linkography. Addressing the taxonomy of qualities for the creative contributions for each action occurring is vital to capture the transformation or change events from procedural to contextual components and vice versa.

The quantitative method aimed at identifying the nature of hierarchical structure and depth for the networks of relations for each action occurring using integration and centrality measurements, while the character strings of information evaluated complexity, rate of information and probability. We conclude that there are two types of structure from which creative insights evolve: 'deep structure' (actions depending on preceding ones), or 'shallow structure' (actions independent from preceding ones). Total independence shows no relation at all of backlinks with the preceding actions in the linkograph, which may reflect the case of drastic paradigm change occurring, provided that the value of the new design concept is addressed in the reasoning process and in the subsequent decisions and final artefacts.

10.3.2 Interpretation of Creative Discovery and Associated Phenomenon in the Design Reasoning Process

We directed our contribution to knowledge to interpret the emergence of insights, evolution of ideas and formation of novel concepts in the design process, which can be classified in three points.

First, identification of forms of design 'reasoning' and 'creativity'. We were able to identify the relation between 'contents of design' (sketching episodes) and 'structure of reasoning' in the design process through the stages of transformation and sudden paradigm shifts, to detect the type of creative insights (critical actions) and the role of reflective practice on the evolution of thoughts, actions, and creative ideas. Design reasoning is 'incremental' when the action (mental insight) reframes the prevailing solution and it is non-rational when the sudden action (breakthrough) restructures the design problem entirely and shifts the concept to another state.

Second, detection of the configurations of reasoning in linkography. This contribution refers to the identification of the configuration of thinking in linkography networks. Divergent and convergent thinking processes, incremental and non-incremental forms of reasoning are all configured, demarcated and described in linkography and network analysis. This proposition is advanced to draw conclusions on models of 'synthesis' and 'creativity' across the design experiments.

Third, taxonomy of quality of creative contribution for the design actions and sudden mental insights and the role in design reasoning. From the identification of the gradual transformation of imagery through sketching episodes, we detected the occurrence of actions and insights through the design processes and drew conclusions about taxonomy of 'qualities' of the 'creative contribution' that identify the roles of those actions and insights in the reasoning process.

10.3.3 Directed Linkography Methodological Development of a Descriptive Method to Analyse the Design Reasoning Process

This study introduces a new method of looking at evolving design moves and critical actions by considering the time of emergence in the structure of the reasoning process. Directed linkography compares two different situations: the first is synchronous, looking at relations back to preceding events, and the second is diachronic, looking at the design state after completion. Using detailed ethnographic observations of designers working on an architectural design task, and coding these using linkographs, the study identifies two poles of design creativity: incremental improvement and the sudden insight.

Deploying a hybrid approach of inductive and deductive research methods aims to develop a protocol method while describing and looking at the nature of creative discovery in design processes. The correlation between quantitative and qualitative analysis is a novel approach to detecting the role of reflective practice in the evolution of design actions and sketching episodes.

Further, we advanced a quantitative method to acquire information from linkography protocols by implementing a variety of measurements to evaluate the evolving actions and design artefacts through different characteristics. While those measures are interpreted in correlation with the qualitative judgements for the interim artefacts, relevant predefined hypotheses are examined to test the reliability and validation of definitions, in addition to the transcription, segmentation and coding schemes. This model is self-regulating; being centred on qualitative and quantitative analysis, the segmentation and coding scheme is corrected through the correlation of quantitative and qualitative results. This method helped to investigate the questions: *How can we capture the emergence of 'sudden mental insight' and detect their role in the structure of reasoning in the design process*? and, *How can we detect the relation between the 'contents' and 'structure' in the design process*? To this end, we outline the following outcomes, which are related to the proposed method, after reaching the saturation phase of experiments (however many design experiments were included, we got the same results for the segmentation and coding scheme).

- **Qualitative Model**

Evolution of ideas and emergence of creative actions are dependent on the 'reflections-in-action' and 'reflections-on-action' between the mind and the artefacts. Our approach to identifying the mental representations of imagery and perception using a variety of cognitive structures was developed from the literature of Schön's model of 'reflective practice' (1983), the 'dialects of sketching' (Goldschmidt, 1994), 'distribution of cognition' (Hutchins, 1995), and 'perception-in-action' (Tschimmel, 2010). We outlined the relations between these aspects, identified the gaps in research and created an integrative theoretical approach for the qualitative model. Figure 10.1 outlines areas of interrelationship between the key aspects of imagery and perception.

Design is a 'reflective process', where the designer/architect initiates an idea, draws it into spatial design configuration (external artefact), and the idea transforms and develops through the process of reflection between the mind and interim artefacts. It is a 'reflective conversation with the design situation' (Schön 1983). Abdelmohsen and El-Khouly (2009) explained the reflective practice with artefacts thus:

It typically starts with critical reflection, where the individual's ideas are questioned, followed by a process of learning from positive or negative experience. It results in developing a rationale for subsequent strategies and actions informed by critically examined values about methods of practice and why they are performed in one specific way or another. This systematic inquiry develops through continuous reflection, or reflection-in-action as coined by Schön (Abdelmohsen and El-Khouly, 2009: 1318).

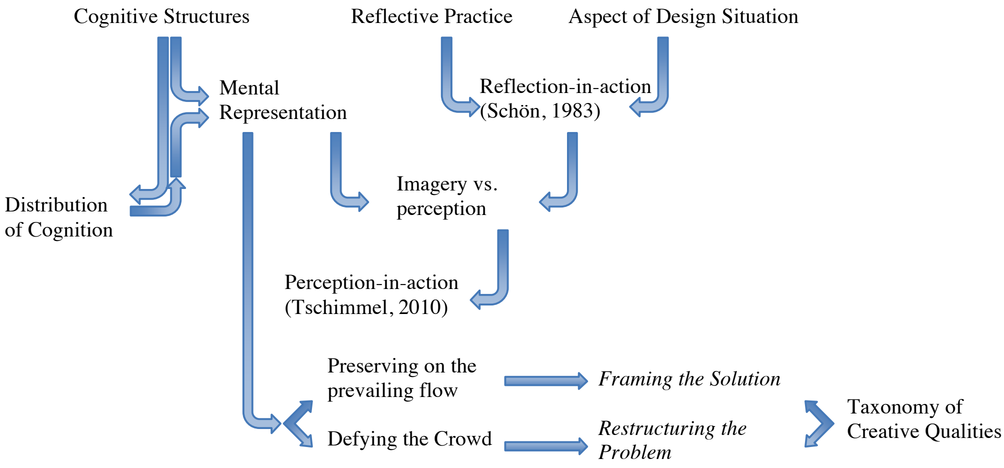


Figure 10.1 Areas of interrelationship between the key aspects of 'imagery' and 'perception'

Our approach to capturing the structure of reasoning through reflection considers the 'designing episodes' the main outcome of reasoning, which includes sketching episodes and visual material, cognitive actions, verbalisations and idiosyncrasy. We considered Goldschmidt's taxonomy of types of sketching in our investigation (Goldschmidt, 1994); sketching 'from' and 'back' to the mind; to generate ideas, to transform imagery into new forms of configurations and to generate new imagery of forms. This approach consists of the following stages:

- *Segmentation:* is a sketch-based model; a 'one-concept' sketching activity is considered an episode that might comprise more than one utterance or in some cases the whole sketching episode is considered as one utterance in the linkograph if it has been made without any transformation of the idea and without any pauses of activity. Nodes can be identified in the following cases:
  - Reflections on artefacts: reflection-in-action with the interim outcomes of design that changes the flow of sketching and transforms the idea is expected to divide designing activity into a series of sketching episodes and utterances.
  - Idiosyncratic actions: thinking-pauses, gestures, switching design tools, exchanging sketches (alternations), back/forelinking ideas, flipping drawings around, tracing over and rescaling are all counted as design utterances (moves).
  - Ethnographic analysis of verbal protocols: searching for conceptual phrases and keywords, finding any common relation between design utterances and confirmation words, Q/As, sentences that explain the design concept(s) are also checked in this model.

- *Coding:* design moves are coded based on types of contribution into the creative process. Two major sets are included: (1) actions that 'preserve' continuous reflections with the mind, and (2) actions that 'defy' continuous reflections and transform the process instead. Preserving reflection proceeds on the initial former concept, taking various forms of activity, such as replication, redefinition or advanced incrementation. Defying reflection introduces a new item to the current state of design, showing taxonomy of actions that change and restructure the whole design situation, such as divergence, synthesis and reconstruction.

- *Linking sketching episodes:* this model operates on a macroscopic scale of coding the design process in terms of sketching episodes. Each drawing projection, diagram or scribble is treated as a single sketching episode. Episodes that might contain tiny or trivial detailed actions are disregarded in order to preserve the hierarchical structure of reasoning and to avoid flattening the process and thus losing the meaning of coding the dependency relations. Throughout drawing actions, the designer might add tiny details to the sketch that are meaningless to count, for instance drawing a few working lines or scribbles. Once the sketching episodes are transcribed into single units, perceptual relations and comparisons are searched for to find any commonalities.
- *Linking drawings and thoughts between different sketching media:* dependency relations occur when the designer switches design actions and transfers knowledge from one sketch to another. This switch might be: an intention to enhance an earlier drawing, continuing the former flow, reflecting on the idea by adding details of more elements, drawing another projection of the idea, or, on the contrary, changing the whole flow to a wholly different concept.

A medium sketch has starting and ending points. It begins when setting up the medium to draw and ends when the designer switches to another one. Interactions, iterations on the sketch and scribbles can be tracked via certain nodes to investigate their relations with the following medium. A design concept starts by doodling an idea, extending the concept to explore different aspects, adding more details, then presenting the whole artefact with shadows and colours, and so forth. In tracing over a sketch, the second medium has relations with most of the drawing actions that were made in the first one (tracing reference). Thus, it has relations with one or more points in addition to the starting point of the first sketch.

- **Integration with Quantitative Model**

Various measurements can be processed over the linkograph on a single node level. Outcomes are compared and correlated with qualitative judgments on the sketching episodes to suggest the possible relationships between design utterances. In this way, each approach reforms the findings of the other (the quantitative indication of any design move, action or emergent artefact must be judged in the qualitative description of concept development –change from one state to another – in order to be classified as a creative insight action) – the decisions that are taken to segment the episodes and code the relations – in a way that provides the researcher with extra details to objectify the analyses. Thus this model provides a designer analyst with an objectively structured soft platform in order to overcome any misjudgements or subjective interpretations on the whole protocol analysis procedures. The quantitative approach comprises three different measurements groups:

- *Information measures:* applied to strings of bits of information that can be extracted for each node in the linkograph (El-Khouly and Penn, 2012a) at the level of unitary-based utterances. Measures of deterministic information theory (Titchener, 1998a; 1998b; 1998c, 2004; Speidel, 2008) are t-complexity, t-entropy and t-information.
- *Network analysis:* to analyse the strength of nodes in a whole network, such as centrality measures: betweenness and closeness.
- *Syntactical measures:* retrieved from the space syntax theory; such as integration and real relative asymmetry (RRA). The rationale for adopting syntactical measures to quantify design process is that linkographs share characteristics of multilevel complexity and hierarchical networks similarly to urban graphs. The integration measure, for instance, senses the split in the linkograph when two sub-networks are disconnected and indicates an obvious fluctuation rather than any other measurements.

Consequently, qualitative judgements on the segmentation and coding processes can be contrasted and correlated with those three categorical quantitative measures on a single node level and readjusted against any misjudgements or subjective interpretations. The model then operates as two-way reforming method.

- *Segmentation process:* is a sketching-based model, in which 'one-concept' sketching activity is considered an episode (utterance) in the linkograph:

- Reflections on artefacts: any reflections between the mind and design products that are featured to change the flow of sketching are considered to split the designing activity into a series of sketching episodes
- Idiosyncratic actions: thinking-pauses, gestures, switching design tools (pens), exchanging sketches (alternations), flipping a certain drawing around to trace over, rescaling a drawing, are all counted as design utterances (moves)
- Verbalisations: confirmation words, Q/As, sentences that explain the design concept(s) are also utterances in this model

- *Coding process:* the design moves are hence coded based on the types of contribution to two major sets: (1) actions that preserve continuous reflections with the mind, and (2) actions that defy continuous reflections. Preserving reflection proceeds on the initial concept and takes various forms of activity, such as replication, redefinition or advanced incrementation. Defying reflection introduces a new item to the current state of design and owes a different taxonomy of actions that operate to change the design situation, such as divergence, synthesis and reconstruction.

The outcomes of processing the integrated model on a wide range of architectural case studies determine the following points:

- Reading patterns of cognitive styles via linkography, where an insightful process resembles intuition is distinguished with a disparity pattern and long back/forelinks. A systematic style is consistently structured, and includes a compact dense pattern of links resembling an incremental process.
- A reliable procedure to identify the creative insights via correlating the significant nodes in both the quantitative and qualitative models, knowing that: our tendency to develop a quantitative approach is to indicate those nodes that are highly integrated or segregated (syntactical model view), or deliver high complex and probability (information measures view), or are highly linked (network analysis view) and correlating those values with the outcomes of qualitative judgements on the sketching episodes.
- Marking up insights over the linkograph investigates the pattern effect 'before' and 'after' the emergence.
- A classification of nodes for each type of a creative insight: sudden insights appear to split the network and act as a bridging/transferral nodes, while incremental insights appear in dense patterns with chunks of links.
- Forms of structuring the design process: for instance, *retrieving analogies* is a means of repossessing information in a way that structures the design process and following products accordingly to that analogy. Retrieving knowledge and information from sources such as the design brief also structures the process and products to certain conceptual elements.

To summarise, coding relations in a linkograph is mainly based on checking the states of appearance and absence of changing concepts, representations, functions, the reasons for new fittings and installations, variations in spatial configurations and so forth. It is chiefly about tracking reflections with respect to their order of occurrence in the context of the interim productions of artefacts to construct an adequate linkograph. The following section presents a procedure to integrate quantitative measures with qualitative judgements in an approach to build up an objective integrative model to describe the design process. Table 10.1 presents the procedure and order of analysis in the proposed model.

Through the application of this empirical, content-based, descriptive model that integrates qualitative and quantitative analysis into one framework, findings of this methodological approach reveal the role of 'sudden mental insight' on the structure of reasoning during the design process. A sudden insight restructures the design problem, reformulates the goals and shifts the situation from one state to another when the emergent action is unprecedented. However, it is incremental when the emergent action refers to memory and reframes the prevalent concept, known as 'memory retrieval'.

This methodological proposition associates media and tools of design (e.g. freehand sketching, CAD) and the emergent interim artefacts in order to identify the dependency relations between design episodes and through the structure of events. The segmentation model aims to detect the role of exchanging ideas via switching media and 'back/forelinking' on the occurrence of design actions through linkography.

Table 10.1 The integration of qualitative and quantitative approaches in one model

#	Phase	Details
1	***Transcription***	Transcribing the design activities according to the time of occurrence
2	***Interim artefacts***	Setting out the interim outcomes in the order of emergence (design artefacts, sketches etc.)
3	***Identification of design episodes***	Processing the qualitative/cognitive model by identifying each design move according to the notion of 'reflection-in-action'
4	***Coding process***	Coding the relations between the externalised drawings and activities. In this phase, the dependency relation is looked at through two angles: 1) The relation between each pavilion and the first set of design elements (the interim artefacts and initial conceptual elements) 2) Pair-wise comparison between sequential pairs of drawings. This is to investigate the lateral transformation and search for any sudden insight that might occur in the prevailing flow
5	***Reflection-in-action***	Finding the 'reflections' and 'back-reflections' among the sketches to classify a hierarchy of the products
6	***Linkography***	Drawing the linkograph
7	***String computation***	Processing the quantitative model (t-code measures) - Setting out a matrix of relations - Processing the t-code algorithm
8	***Archiography***	Drawing the archiograph (another representation of the linkograph but it reflects the relations in a clearer way)
9	***Comparisons***	Comparing the archiograph with a hierarchical classification of the interim artefacts
10	***Correlations***	Checking whether correlations exist between the quantitative model and qualitative judgements

10.4 Limitations of Study

The shortfall in the developed segmentation and coding scheme is threefold:

First, segmenting and coding the design process is *labour intensive*. The remedy is to extract large segments, which permits analysis of longer designing episodes. This relates to our proposition of judging sketching episodes as the external representation (outcomes) of the thinking process hypothesised to capture the structural units of reasoning through coding the relations between design moves and activities and construct the linkograph.

Second, reaching acceptable values of inter-coder reliability is difficult to achieve, particularly if there are long verbalisations by the designer to explain his/her work, which may pertain to several topics at once and thus suffer incoherency. Coders may rely on their own interpretations, which are sometimes quite speculative. This may cause differences among codes, and even among the codes used by the same coder in different instances.

10.5 How the Research Relates to Professional Stages of Work

We outline three paths to relate this research to professional stages of design work with the aim of achieving methodological development for modelling the design process, including advanced design technology in the way we look at design cognition and creativity and bridging this field of design studies with the research area of building information modelling (BIM), to benefit from a wide and diverse spectrum of information and data sets of multidisciplinary processes in decision-making, and to adopt the concept of 'lean construction' and 'six-sigma' in the design process to conserve the cognitive behaviour and efforts of the designers and stakeholders. Themes for future work are:

10.5.1 The Role of Advanced Designing Applications in Design Stages

As declared through the exploratory pilot studies and methodology of empirical research at the beginning of this dissertation, we can test the effect of the means, modern tools and advance design applications on the emergence of mental insights and to support quick and axiomatic transition from one conceptual presentation to another. Further, modern applications might play an imperative role on the reasoning process; either by framing the prevalent conceptual idea under development (prevailing during the preliminary design stages) or by restructuring the entire design problem. We classify modern design tools and advance applications into three main areas:

- Conventional: e.g. freehand sketching and CAD software
- Parametric: setting the parameters to adapt the design form on, e.g. Grasshopper© and Generative Components©
- Generative: aids to innovate unpredicted forms, e.g. processing©

The main objective of this theme is twofold: (1) to contrast the authorship of creativity, the authorial control of novel concept, with advanced design applications – 'conventional' versus 'parametric' versus 'generative' design tools; (2) to evaluate the role the design brief plays (including or excluding conditions and specified programme) in the design process, either hindering the deployment of programming facilities or contributing to it.

To outline the required principles to initiate a comparative study between different design applications, we must know how to distinguish between each design approach. Parametric design is a process-oriented approach where the parameters must be set up at the initiation phase and the stages of development are then based on these. These parameters could be difficult or impossible to change later, particularly at the ending phases, which require high-calibre expertise in using the parametric tool and a comprehensive vision towards the final product that might be unimaginable at the initiation phase. In the parametric design process, the architect has an expectation at the beginning of how the end result will look. In generative design, on the other hand, there is no expectation at the beginning of design process. The generative programme (script) generates a form that the architect could not imagine at the initiation phase. It runs algorithms that could help to innovate and visualise unprecedented and unpredicted forms. Generative design applications include neural networks, genetic algorithms, and adaptive application to environmental aspects.

The design brief might constrain the designer from deploying any of the programming tools, either parametric or generative. Traditional design briefs and functional programmes should be written allowing freedom for the architect to explore the variety of techniques and capabilities to generate non-traditional forms and solutions. Our pilot experiments with architects using Processing, Generative Components®, Rhino® and Grasshopper™ indicated that the design brief should consider the nature of digital tools and provide freedom of exploration. For example, to generate 'a responsive wall to light' is entirely different from outlining the functional programme with detailed specifications to design a 'cheese factory'.

Generally, the way the architect manages the design process could be through using more than one tool or design technique. It is important for design researchers to investigate the 'engagement with' and 'attachment to' certain concepts in switching from one intermediate design medium to another (switching the mind-set to a new state), with the aim of asking:

- Does the transition from one representation to another reframe the concept or restructure the problem?
- Does it help to overcome any phases of stagnation or fixation?
- How far is the designer engaged in a specific representation due to a certain design application?

Does the transition between two design media (e.g. applications, sketches, models) and exchange between representations contribute to the emergence of sudden mental insights?

10.5.2 The Impact of the Procedural and Contextual Components on Developing Design Tools and Digital Applications in Creative Thinking

From observing architects while designing using a variety of computational tools (software applications such as the parametric software of Grasshopper™ algorithmic for Rhino®, Generative Components®, or the advanced modelling and animation tool of Maya or 3D Studio Max®), it can be seen how procedural the actions are to execute items of forms and shapes, where the actions are quite dependent and consecutive. Each command action to the software is visited once to execute a particular entity of form.

This approach to design targets the execution process instead of allowing creative thinking to take place while designing. The pattern of reflection-in-action is limited to some extent. If a new insight is received in the designer's mind to redesign a form, the process requires re-initiation because once the parameters are set in such software it is difficult to reset again to redefine the parameter except from scratch.

Although Maya is a very recent tool for creating architectural forms, it also constrains the designer from rethinking his/her process while limiting creativity to bring unexpected ideas forward to the design discourse of such procedural process. If design is believed to be a reflective process that should benefit from multidisciplinary design tools, computational techniques should often allow reversible lines during the process and should also allow for hybrid tools to take part and intervene in the design process. Architects often switch tools and computational applications along the way while thinking about, drafting and completing the architectural spatial forms. It was observed in the pilot experiments that the form might be divided into several tasks with each designed via a particular tool. We raise the question: Could advanced computational tools allow contextual components to be part of the design process?

Yet to some extent we can only experiment with the computational tools that are available and observe how designers are able to use them while designing. In looking at this theme for future work, it is proposed to direct computational design research towards developing more flexible and creative architectural software (tools). To develop a new software that considers both procedural and contextual components will help the designer to think about and execute the design form, benefit from the reflection-in-action process with the artefacts, and change forms all the way (from state to another) swiftly and creatively. Therefore, this dissertation is entitled: 'Contextual and Procedural Components in the Creative Thinking Process' to illuminate the importance of addressing those elements for better designing for the architect, 'tool-user', 'user-programmer' and 'tool-programmer'.

10.5.3 How Can We Take Advantage of 'Continuous Improvement', 'Six-sigma', and 'Building Information Modelling' in Multidisciplinary Design Process?

Concepts of 'continuous improvement', 'six-sigma' and 'lean-construction' were introduced to the field of design construction a long time ago but were not taken into consideration by most design cognition researchers until now. In the real world, architects collaborate with engineers of different specialities and other stakeholders (e.g. client and community as well as contractors and suppliers) in the design and construction processes. It is better for architects to be aware of these principles at the early phase of concept initiation to create the design concept in accordance with them and to avoid any drastic changes that may occur while consulting with the contractors and engineers in the following execution phases. Adoption of these concepts will save time and cognitive efforts to amend the design concept and pertinent drawings throughout the process, and also provides a shared knowledgeable source for the decision-making process.

On the other hand, building information modelling provides a platform to organise datasets of the stream of information amongst the design stakeholders, which can be deployed to improve the decision-making process and be utilised at the early stages of conceptualisation. In the UK, the Construction Project Information Committee (CPIC) is responsible for providing best practice guidance on construction production information supports the adoption of building information modelling (BIM) in design and construction processes. The National BIM Standard (United States) defined building information modelling as:

a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life-cycle; defined as existing from earliest conception to demolition.[107]

10.6 Implications On Other Research Domains

We identify two paths of implication on other research domains with the aim of achieving integration bridging between design research, neuroscience, and cognitive studies.

10.6.1 Theme I: Empirical Evidence on the Neural Activity Associated with Sudden Mental Insights

This approach aims to bridge the gap between the neurological studies and the characterisation of design as a distinct cognitive phenomenon. Functional magnetic resonance imaging (fMRI) technology has witnessed remarkable developments in recent years in scanning the activity of neurons in the brain during human activity. Deploying this technology to gain empirical evidence of the association between the events taking place in the design process and the phenomenon of sudden mental insight is proposed to be correlated with our model and provide profound insights to understand design creativity.

Overlaying the linkograph protocol with another layer of 'neuro-imaging' evidence will promote the transcription and coding schemes to investigate the dependency relations between the design actions with further insights. Through correlation between the proposed descriptive model and brain activity, objective and comprehensive understanding is provided on the context behind the emergence of sudden mental insights and creative actions, whether dependent on the preceding events or utterly independent, the effect on the reasoning process, and understanding the association between the design episodes.

At Birkbeck-UCL Centre for Neuro-Imaging (BUCNI), Institute of Cognitive Neuroscience and Division of Psychology and Language Sciences, University College London, Alexiou et al. (2009) explored the neurological basis of design cognition by deploying brain-imaging technology (Alexiou et al. 2009; Gilbert et al., 2010). Building on the assumption that the brain has a 'modular' organisation, meaning that it is 'structurally and functionally organised into discrete units of 'modules' and that these components interact to produce mental activities' (Gazzaniga, 1989: 947), their intention was to investigate the neural basis of cognition, and particularly to understand how cognitive functions are supported by different brain areas.

Neuroscience and brain imaging studies have generated important evidence associating specific brain regions with visual cognition. Alexiou et al. (2009) outlined that by monitoring and comparing the activation of these regions during 'design' and 'non-design' sessions, exploring the role and importance of visual thinking in design and its relation to other types of cognitive functions will provide additional evidence to support or refute theoretical hypotheses. Unravelling the association of design thinking with the activation of different brain regions was proposed to make more informed decisions about design and creative problem solving.

However, Alexiou et al. (2009)'s study is limited in the length and nature of design experiments they deployed towards outlining their conclusions. Further, the phenomenon of sudden mental insights was not the main objective in this study and the type of design problem was simplified to the arrangement of furniture in a bedroom. Due to the limitation of fMRI technology at the time, the design experiments were limited in length to a few minutes to capture the brain activity in time frames of a few seconds – the time constraints imposed by the brain imaging methodology. Thus design tasks have to be complex enough to qualify as 'prototypical' design tasks. On the positive side, this research study outlined the differences between ill-defined and well-defined experiments.

10.6.2 Theme II: Structured Imagination versus Structured Creativity

Ward et al. (1999) posed the question: Is cumulative creative progress the providence of a small set of geniuses or should the glory be spread more broadly? Three points were outlined to investigate this question: (1) human cognition resides on 'generative capacity' to move beyond discrete stored

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[107] National BIM Standard United States, National Building Information Model Standard Project Committee, http://www.nationalbimstandard.org/faq.php#faq1 (Accessed 8 April 2014).

experience, (2) the processes that underlie this 'generativity' are open to rigorous experimental investigation, and (3) creative accomplishments are based on ordinary mental processes that are observable.

To enquire whether creativity is 'structured' or 'arbitrary', Finke et al. (1992) and Ward et al. (1999) identified some concepts to investigate from observing individuals (novice and expert) solving problems. These concepts are: 'family resemblance', 'extending concepts', 'recently activated knowledge', 'conceptual combination', 'creative imagery', 'goal oriented versus exploratory creativity', 'domain specific versus universal creativity skills', and 'structured versus unstructured creativity'. These principles were adopted to observe a group of students who were requested to imagine animals that might have lived somewhere else in the galaxy. They found that when subjects created a new member of a known category for an imaginary setting, their imagination was structured by a particular set of properties that were characteristic of that category.

Yet posing the question 'is design creativity governed by certain rules?' requires us to examine the architecture design process in two phases: the first relates to concept emergence – the aim of this dissertation – and second is to investigate the evolution of forms of building types over a wide time period. This can be divided into two subsets: to detect the prime conceptual solutions and products for a certain building type across a group of architects at a certain time (synchronic cross-case analysis), or to study the design products and outcomes for a particular pioneer architect (diachronic analysis).

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Appendices